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Context: Evidence-based practice (EBP) has become a point of emphasis in athletic training education and clinical practice. One approach to EBP is utilizing clinical prediction models (CPM) to assist clinicians in the screening, diagnosis, prognosis, and treatment of injury. A number of isolated risk factors, which can be categorized as: (a) self-report outcome scores, (b) sport performance factors, or (c) functional performance measures (FPMs), have been identified and suggested to be causal with regard to upper-extremity (UE) sports related injury (SRI) in baseball athletes. ***Objective***: to develop a preliminary CPM for UE SRI derived from multiple factors specific to self-reported outcome measures, sport performance risk factors, and FPMs. ***Design:*** Retrospective cohort study. ***Setting***: National Collegiate Athletic Association Division I baseball program. ***Subjects:*** Thirty-six athletes who completed the preseason pre-participation examination, the Kerlan-Jobe Orthopaedic Clinic overhead athlete shoulder and elbow score (KJOC-SES,) and the Targeted Enhanced Athletic Movement Screen (TEAM-S). ***Main Outcome Measures:*** Independent variables for this study included the self-reported outcome measures (KJOC-SES), sport performance risk factors, and FPMs (TEAM-S). The dependent variable for this study was self-reported history of UE SRI. ***Results***: Univariate analyses identified nine predictor variables that differed between injured and non-injured athletes ($p \leq 0.10$): KJOC-SES, playing position (pitcher), single leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder

mobility test non-throwing arm, CKCUEST (TEAM-S score), and CKCUEST (absolute score). Forward step-wise logistic regression yielded a resultant two-factor clinical prediction model consisting of playing position and KJOC-SES. The two-factor CPM based on KJOC-SES scores ≤ 86 and playing position (pitcher) yielded diagnostic utility measures as follows: Sensitivity of 83% (95% CI: 0.55 to 95); Specificity of 95% (95% CI: 79 to 99); Positive likelihood ratio of 22.0 (95% CI: 2.88 to 138.5); and negative likelihood ratio of 0.17 (95% CI: 0.04 to 0.61). ***Conclusion***: A preliminary two-factor CPM comprised of KJOC-SES (≤ 86) and playing position (pitcher) retrospectively predicted UE SRI in a cohort of baseball players with strong diagnostic utility.

A PRELIMINARY CLINICAL PREDICTION MODEL FOR UPPER-EXTREMITY INJURY IN COLLEGIATE BASEBALL: A SINGLE-CENTER RETROSPECTIVE STUDY

By

Daniel Thomas Tarara

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

The concepts of evidence-based practice (EBP) have recently become a point of emphasis in athletic training clinical practice (BOC, 2010; NATA, 2010). Coinciding with this, educational reform in entry-level athletic training education has established competencies related to the development of EBP knowledge and skills (NATA, 2011). Although EBP may seem new within athletic training professional practice and education, the concepts have been well established in other healthcare professions for over 25 years (AMA, 2002; Guyatt, Rennie, Meade, & Cook, 2008; Sackett, Straus, Richardson, Rosenberg, & Haynes, 1997). The lag in athletic training's alignment with EBP was formally recognized in 2004 (Hootman, 2004). Initiatives by the National Athletic Trainers' Association (NATA) and Board of Certification (BOC) have raised awareness of the importance of EBP; however, advances in evidence–based (EB) clinical research are still lacking in the field.

One approach to EB clinical research relates to the development of clinical prediction models (CPMs). CPMs are statistical models used to estimate probability related to screening, diagnosis, prognosis, or treatment interventions (Aronoff et al., 2010; Banks, Gilmartin, & Fink, 2010; Hicks, Fritz, Delitto, & McGill, 2005; Jewell, 2011; Steyerberg, 2010). A combination of factors relating to patient history, pathophysiology, symptomology, risk factors, test results, functional performance

measures (FPMs), and subjective outcome measures can be clustered to aid in clinical decision-making (Bainbridge, Nasmith, Orchard, & Wood, 2010; Banks et al., 2010). This approach is a departure from an overreliance on single factors or heuristics for clinical decision making (Bainbridge et al., 2010). CPMs can subsequently be an important tool for enhancing clinical practice (Atiya, 2002) and provide clinicians with the ability to gain clarity when confronted with uncertain or complex patient cases (Bainbridge et al., 2010). The utilization of CPMs is predicated on combining existing evidence, patient preference, and clinical expertise to reach an informed clinical decision (Glynn & Weisbach, 2011), which in turn are the foundational components of EBP (Guyatt et al., 2008; Jewell, 2011; Sackett et al., 1997).

CPMs should be considered an effective method of improving patient-oriented health care (Haworth, Hopkins, Ells, Ackroyd, & Mowat, 1981). This approach is in contrast to traditional biomedical research models (Portney & Watkins, 2009), which emphasize a causal or linear relationship between pathology and subsequent impairments (Portney & Watkins, 2009). Although the two strategies may seem parallel, the biomedical research strategy does not commonly account for the psychosocial dimensions of how a patient is affected by injury or illness. This is most evident in biomedical injury prevention paradigms which center largely on etiology, internal and external risk factors, incident rates, and categorization of mechanisms (Bahr & Krosshaug, 2005; Chalmers, 2002; Van Tiggelen, Wickes, Stevens, Roosen, & Witvrouw, 2008). Although there is a strong relationship between the biomedical model and sports related injury (SRI) epidemiology, the model often fails to include the self-

reported outcome measures in approaching diagnostic, prognostic, and treatment strategies (Finch, Gabbe, et al., 2011; Finch, Ullah, & McIntosh, 2011). This indicates a need for patient-centered research models (Hawk, Long, & Boulanger, 1998; Sauers & Snyder, 2011) that advance clinical practice (Snyder et al., 2008; Valovich McLeod et al., 2008).

Self-reported measures for determining functional disability in clinical research have received recent consideration (Cosby & Hertel, 2011; Evans & Lam, 2011; Mattacola, 2011; Michener, 2011; Parsons & Snyder, 2011). Specific to the current investigation, self-reported outcome measures have served as a tool for quantifying functional disability in upper-extremity (UE) athletes (Alberta et al., 2010; Domb et al., 2010; Neuman et al., 2011; Sauers, Dykstra, Bay, Bliven, & Snyder, 2011; Thigpen & Shanley, 2011). Development and validation of these self-reported outcome measures have been important initial steps in quantifying injury risk stratification and treatment outcomes (Alberta et al., 2010; Thigpen & Shanley, 2011). Qualifying functional status through outcome measurement scales represents a departure from relying on return-to-play (RTP) as a benchmark for successful treatment outcomes in high functioning athletic populations (Conway, Jobe, Glousman, & Pink, 1992). Although RTP is a common term, a standardized definition has not emerged in literature. This can contribute to confusion and disagreement between clinicians as to what criteria best define a successful treatment outcome (Creighton, Shrier, Shultz, Meeuwisse, & Matheson, 2010). Specific to overhand-throwing athletes, qualifying successful treatment outcomes have been problematic because RTP is not sensitive in determining functional status (Alberta et al.,

2010). Such problems are highlighted by reports of professional baseball players who RTP but still present with functional limitations: e.g., pain, weakness, instability, loss of power, altered mechanics, and loss of pitch control (Domb et al., 2010; Neuman et al., 2011). Subsequently, the inclusion of self-reported outcome measures should be an important component of developing a CPM.

Baseball is a popular international sport and is played on youth, high school, college, and professional levels. The epidemiology of SRI in baseball has been widely reported (Dick et al., 2007; Hootman, Dick, & Agel, 2007; Janda, 2003; Kerut, Kerut, Fleisig, & Andrews, 2008; Lyman & Fleisig, 2005; Magra, Caine, & Maffulli, 2007; McFarland & Wasik, 1998; Posner, Cameron, Wolf, Belmont, & Owens, 2011). Baseball, in comparison to other sports, has a relatively low overall injury rate of 0.23 per 1,000 athlete exposures (Hootman et al., 2007). However, the rate of UE SRI for baseball players increases in relationship to competitive level with a reported 5% in little league and high school (Fleisig et al., 2010), 25% in collegiate (Dick et al., 2007), and 50% in professional (Anz et al., 2010). Over the past decade there has been a disproportionate rise in UE SRI necessitating surgery (Petty, Andrews, Fleisig, & Cain, 2004). This trend had been described as an injury epidemic (Fleisig, 2012) and has led to a call for further clarification in understanding the relationship between risk factors and injury (McHugh et al., 2012). Within this population, clarifying the relationship between risk factors and UE SRI is complex because most athletes who sustain injury present with multiple risk factors (Petty et al., 2004). In this respect a CPM specific to UE SRI in baseball would be beneficial in advancing the body of knowledge in this area.

A number of intrinsic risk factors have been identified and suggested to be causal to UE SRI in baseball athletes. These risk factors include: muscle strength deficits (Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988; Yildiz et al., 2006), muscle fatigue (Mullaney, McHugh, Donofrio, & Nicholas, 2005); internal and external strength imbalance (Lewis & Valentine, 2007); glenohumeral internal rotation deficient (GIRD) (Borsa, Dover, Wilk, & Reinold, 2006; Dines, Frank, Akerman, & Yocum, 2009; Wilk et al., 2010); scapula dyskinesis (Cooper, Donley, Verna, & Morgan, 2002; Kibler & McMullen, 2003); maximum pitch velocity (Bushnell, Anz, Noonan, Torry, & Hawkins, 2010); pitching volume (Fleisig et al., 2010; Olsen, Fleisig, Dun, Loftice, & Andrews, 2006); pitch type (e.g., slider , curveball) (Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998; Fleisig et al., 2010; Fleisig et al., 2006); playing position (Fleisig et al., 2010; Olsen et al., 2006); throwing biomechanics (Fleisig, Andrews, Dillman, & Escamilla, 1995; Fleisig, Barrentine, Escamilla, & Andrews, 1996); and low self-reported functional assessment measures (Alberta et al., 2010; Domb et al., 2010; Neuman et al., 2011). These risk factors can be categorized into three areas: (a) self-report outcome measures, (b) sport performance risk factors, and (c) FPMs. Despite making progress in identifying individual injury risk factors, a single multifactorial injury prediction model that accounts for these three risk factor categories has not been presented in literature.

The studies that have identified a broad range of injury risk factors relating to UE SRI in baseball have been largely descriptive (Fleisig et al., 2010; Mueller, Marshall, & Kirby, 2001; Olsen et al., 2006). Corresponding analyses have been dominated by traditional statistics (e.g. correlations, descriptive distributions) verses Bayesian inference

(e.g. sensitivity, specificity, likelihood ratios). A Bayesian approach provides an advantage in establishing inference based on observed data (Wagenmakers, Lee, Lodewyckx, & Iverson, 2008) and can be applied clinically to improve diagnostic and prognostic decision-making (Guyatt et al., 2008). The utilization of Bayesian statistics in establishing a CPM may be an important step in identifying a set of factors specific to UE SRI in college baseball players to assist in diagnostic and prognostic decision-making. Additionally, such a CPM may be clinically beneficial in identifying low- or high-risk athletes for injury prevention programs based on evidence. To date, we have been unable to locate any CPMs specific to UE SRI in colligate baseball athletes.

Although a number of baseball-specific risk factors have been independently described (Fleisig et al., 2010; Hootman et al., 2007; Olsen et al., 2006; Wilk et al., 2010), a multifactorial model has not been developed to aid in the clinical diagnosis of UE SRI. The collective inclusion of self-reported outcome measures (Domb et al., 2010; Neuman et al., 2011; Thigpen & Shanley, 2011), sport performance risk factors (Fleisig et al., 2010; Olsen et al., 2006), and FPMs (G. Cook, Burton, & Hoogenboom, 2006a, 2006b; G. Cook, Burton, Kiesel, Rose, & Bryant, 2010; Kiesel, Plisky, & Voight, 2007) may be important in establishing a CPM specific to the baseball population.

As a decision-making tool, CPMs have potential to assist in diagnosis, prognosis, and treatment strategies. This is particularly relevant in the context of complex patient groups or injury patterns encountered in clinical practice. Collegiate baseball players are one such specialized patient group and often present with complex UE injury patterns. The diagnosis, prognosis, and treatment of UE SRI in collegiate baseball players are

complex. Consequently, there is a need to improve the decision-making process to assist clinicians in improving patient outcomes. A CPM of UE SRI would be an important advancement in assisting clinicians in navigating the complexities of this patient population. Therefore, the purpose of this study was to develop a preliminary clinical prediction model for UE SRI derived from multiple factors specific to self-reported outcome measures, sport performance risk factors, and FPMs in a retrospective cohort of collegiate baseball players, and to determine if the model is retrospectively predictive of UE SRI.

Objectives and Hypotheses

Objective

To develop and assess a preliminary CPM for UE SRI in a retrospective cohort of collegiate baseball players.

Specific Aim One

Identify individual factors specific to self-reported outcome measures, sport performance risk factors, and FPMs that differ between previously injured and uninjured cohorts. Secondarily to this, through the construction of 2x2 contingency tables we will determine the diagnostic utility (as measured by sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio) of individual factors that significantly differ between injured and uninjured cohorts. We hypothesized that multiple individual factors will be statistically significant in retrospectively predicting UE SRI in a cohort of college baseball players.

Specific Aim Two

Determine whether the individual factors identified in Specific Aim One collectively can retrospectively predict injury status. We hypothesized that a multivariate CPM will retrospectively predict UE SRI in a cohort of college baseball players with a greater degree of diagnostic utility than individual factor diagnostic utility measures.

Operational Definitions

1. The two-by-two (2x2) contingency table used for calculating diagnostic utility values is listed in Table 1.

Table 1. 2x2 Contingency Table for Diagnostic Test Results

		Reference Standard / Target Condition		
		Positive	Negative	Total
Diagnostic Test / Clinical Measure / Risk Factor	Positive	*a* (True positive)	*b* (False positive)	*a* + *b*
	Negative	*c* (False negative)	*d* (True negative)	*c* + *d*
	Total	*a* + *c*	*b* + *d*	*N*

Note. Adapted from Portney & Watkins (2009), and Sackett et al. (1997)

2. Sensitivity: The proportion of subjects with the target condition who will have a positive test result (Guyatt et al., 2008; Sackett et al., 1997; Wagenmakers et al., 2008). Sensitivity = (a/(a + c) (Portney & Watkins, 2009).

3. Specificity: The proportion of subjects without the target condition who will have a negative test result (Guyatt et al., 2008; Sackett et al., 1997; Wagenmakers et al., 2008). Specificity = (d/(b + d) (Portney & Watkins, 2009).

4. Positive Likelihood Ratio (LR+): The probability of a subject with the target condition having a positive test result divided by the probability of an individual without the target condition having a positive test result (Akobeng, 2005). LR+ = sensitivity/(1 – specificity) (Portney & Watkins, 2009).

5. Negative Likelihood Ratio (LR-): The probability of a subject with the target condition having a negative test result divided by the probability of an individual without the target condition having a negative test result (Akobeng, 2005). LR- = (1 – specificity)/specificity (Portney & Watkins, 2009).

6. Diagnostic Odds Ratio (DOR): An index which summarizes a test's accuracy as a single number that expresses how many times greater the odds are of finding a positive test result in an injured versus a non-injured person. DOR = positive likelihood ratio/negative likelihood ratio = (sensitivity x specificity)/(1- sensitivity) x (1-specificity) (Glas, Lijmer, Prins, Bonsel, & Bossuyt, 2003; Macaskill, Gatsonis, Deeks, Harbord, & Takwoingi, 2010).

7. Prevalence: The number of target conditions in proportion to the total sample size at a given time. Prevalence = (a+c)/(a+b+c+d) (Portney & Watkins, 2009).

8. Pre-test Probability: The probability that a target condition exists prior to performing a diagnostic test. Pre-test Probability is equal to the target condition's prevalence (Portney & Watkins, 2009).

9. Pre-test Odds: The odds that the patient has the target condition before a diagnostic test is performed. Pre-test Odds = (pre-test probability)/(1 – pre-test probability) (CEBM, 2012).

10. Post-test Odds: The odds that the patient has the target condition after a diagnostic test is performed (pre-test odds x likelihood ratio) (CEBM, 2012).

11. Post-test Probability: The proportion of patients with a target condition after performing a diagnostic test. Post-test Probability = (post-test odds)/(post-test odds +1) (Portney & Watkins, 2009).

12. Diagnostic Utility: The discriminative potential of a diagnostic test to identify a target condition based on measures of sensitivity, specificity, and likelihood ratios.

Limitations and Assumptions

1. All participants provided honest and accurate health and injury information.

2. All participants performed at their maximum effort during functional performance testing.

3. The findings of this study are limited to the tested cohort.

4. Injury status was established from a self-reported history of injury question as part of the KJOC-SES instrument. The reporting of a diagnosed injury to the shoulder or elbow did not provide information about the time of sustaining an UE SRI.

Delimitations

1. The results of this dissertation are limited to the retrospectively tested cohort and cannot be generalized to a broader population or other UE sports.

CHAPTER II

REVIEW OF LITURATURE

The purpose of this review is to provide supporting information and a framework for a clinical prediction model (CPM) of upper-extremity (UE) sports related injury (SRI) in college baseball players. This model will be developed and assessed by examining select self-reported outcome measures, sport performance risk factors, and functional performance measures (FPMs). This review of literature will encompass the following: (a) evidence-based practice (EBP), (b) CPMs, (c) self-reported injury risk factors, (d) sport performance injury risk factors, (e) functional performance injury risk factors, and (f) UE SRI related to baseball.

Evidence-Based Practice

The EBP paradigm encapsulates a broad spectrum of topics related to the field of medicine. A full review of the paradigm has been presented in a number of seminal works (Guyatt et al., 2008; Sackett et al., 1997). EBP concepts recently have become a point of emphasis in athletic training professional practice (BOC, 2010; NATA, 2010). Coinciding with this, educational reform in entry-level athletic training education has established competencies related to EBP knowledge and skills (NATA, 2011). Although EBP may seem new within athletic training professional practice and education, the concepts have been well established in other healthcare professions for over 25 years (AMA, 2002; Guyatt et al., 2008; Sackett et al., 1997). The lag in athletic training's use

of EBP was formally recognized in 2004 (Hootman, 2004). Initiatives by the National Athletic Trainers' Association (NATA) and Board of Certification (BOC) have raised awareness of the importance of EBP; however, advances in evidence–based (EB) clinical research are still lacking in the field. Specifically there is a need for EB research models (Hawk et al., 1998; Sauers & Snyder, 2011) which advance patient–oriented clinical practice (Snyder et al., 2008; Valovich McLeod et al., 2008).

With respect to this dissertation, primary importance lies in the EBP concepts related to clinical measures and diagnostic test accuracy. The overlap between EBP concepts and Bayesian statistical inference is central in approaching diagnostic questions in the context of clinical practice (Hawkins, 2005). Specifically, two-by-two (2x2) contingency tables provide the foundation for determining the statistical measures of validity (Jewell, 2011; Portney & Watkins, 2009) and testing the significance for categorical frequency (Norman & Streiner, 2008). See Table 1 for an example of a 2x2 contingency table for diagnostic test results.

Traditionally, 2x2 contingency tables are constructed based on a known reference standard and a clinical diagnostic test (Norman & Streiner, 2008; Portney & Watkins, 2009). A reference standard is usually based on a "gold standard" in the context of the presenting clinical question or target condition. In the absence of a gold standard, Bayesian statistical models can also be constructed based on norm or criterion reference variables (Jewell, 2011). A clear or *true* reference standard may not be obtainable in approaching some clinical questions, in which case, dichotomous patient data may serve as a reference criterion standard (e.g., "prior injury" versus "no prior injury") (Portney &

Watkins, 2009). The clinical diagnostic test used in constructing a 2x2 contingency table can encompass a broad range of procedures (e.g., orthopedic special tests, x-ray results, lab work, etc.) but may include any variable with a statistical relationship to the target condition. This allows for the inclusion of unique variables such as self-reported outcome measures, sport performance risk factors, and FPMs as screening or clinical diagnostic tools (Portney & Watkins, 2009).

A 2x2 contingency table provides a means of charting a diagnostic test's four possible outcomes: (a) true positive, (b) true negative, (c) false positive, and (d) false negative (Portney & Watkins, 2009). A true positive test result occurs when a diagnostic test correctly identifies the target condition. For a true negative, a diagnostic test correctly rules out a target condition. A false positive occurs when a diagnostic test is positive in the absence of the target condition. Finally, a false negative response is when the clinical test is negative in the presence of the target condition. Once these values have been tabulated, the validity of a diagnostic test can be expressed in terms of sensitivity (Sn) and specificity (Sp) (Portney & Watkins, 2009).

Sn and Sp are measures of validity for diagnostic tests and are valuable decision-making tools in EBP (Portney & Watkins, 2009). Sn is classically defined as the proportion of patients with a positive test result among those with the target condition (Guyatt et al., 2008; Sackett et al., 1997; Wagenmakers et al., 2008); Sn = (a/(a + c) (Portney & Watkins, 2009). Sp is defined as the proportion of patients without the target condition who will have a negative test result (Guyatt et al., 2008; Sackett et al., 1997; Wagenmakers et al., 2008); Sp = (d/(b + d) (Portney & Watkins, 2009). More simply

stated, Sn is the true positive rate while Sp is the true negative rate (Portney & Watkins, 2009).

The clinical utility of Sn and Sp may be counterintuitive in clinical practice. Diagnostic tests with high Sn are useful at identifying people with a target condition and have a very low false negative rate (Jewell, 2011). Thus, a negative test result is beneficial in ruling out the presence of the target disorder. By contrast, diagnostic tests with high Sp are useful at identifying people without the target condition and yield very low false positive rates (Jewell, 2011). Subsequently, a positive test result is beneficial in ruling in the presence of the target disorder.

In addition to Sn and Sp, positive predictive value (PPV) and negative predictive value (NPV) are measures of probability that are also derived from a 2x2 table (Akobeng, 2007a; Portney & Watkins, 2009). PPV is the proportion of people with a positive test who have the target condition. PPV is considered the post-test probability of a target condition given a positive test (Akobeng, 2007a). PPV = a/(a +b) (Portney & Watkins, 2009). NPV is the proportion of people with a negative test that do not have the target condition; it is considered the post-test probability of not having the target condition given a negative test (Akobeng, 2007a). NPV = d/(c +d) (Portney & Watkins, 2009). PPV and NPV depend upon the prevalence of the target condition represented in the 2x2 contingency table data (Jewell, 2011; Portney & Watkins, 2009). Prevalence in the context of a small sample size may not be a true reflection of the prevalence for a larger population (Portney & Watkins, 2009). Consequently, prevalence may fluctuate naturally over time because of the influence of prevention or treatment strategies (Jewell,

2011; Portney & Watkins, 2009). Because PPV and NPV vary with changes in prevalence (Akobeng, 2007a), these measures are not considered useful for determining diagnostic test validity in clinical practice (Jewell, 2011).

An alternative to measures of PPV and NPV is the measure of probability through likelihood ratios (LR) (Portney & Watkins, 2009). LR can be calculated directly from a 2x2 contingent table; however, in the absences of 2x2 table, LR also can be derived mathematically from reported Sn and Sp values (Akobeng, 2007b; Portney & Watkins, 2009). LR is directionally expressed as positive likelihood ratio (LR+) or negative likelihood ratio (LR-). LR+ is the probability of a subject with the target condition having a positive result divided by the probability of an individual without the target condition having a positive result (Akobeng, 2005; Portney & Watkins, 2009); LR+ = sensitivity/(1 – specificity) (Portney & Watkins, 2009). Conversely, LR- is the probability of a subject with the target condition having a negative test result divided by the probability of an individual without the target condition having a negative test (Akobeng, 2005); LR- = (1 – sensitivity)/specificity (Portney & Watkins, 2009). Clinically, LR+ indicates how many more times likely a positive test result will be found in individuals with the target condition compared to those without the respective condition. LR- indicates how many more times likely a negative test result will be found in individuals with the target condition compared to those without the respective condition. Simply stated, a higher LR+ suggests a greater probability of a target condition while a lower LR- suggests a lower probability of a target condition.

LRs provide three distinct advantages over Sn, Sp, PPV, and NPV measures in determining the probability of a target condition. First, LRs are independent of disease prevalence (Akobeng, 2007b; Jewell, 2011; Portney & Watkins, 2009). Second, LRs can be applied to individual patient cases whereas Sn, Sp, PPV, and NPV are group (data set) specific (Jewell, 2011; Portney & Watkins, 2009). Third, LRs are relevant across the spectrum of test results irrespective of a positive or negative finding (Jewell, 2011). These three factors highlight the clinical utility of LRs in understanding and applying diagnostic test results in clinical practice (Akobeng, 2007b).

The LR+ and LR- are interpreted based on scales of clinical importance (Portney & Watkins, 2009) or through use of Fagan's (Bayesian's) nomogram (Akobeng, 2007b; Guyatt et al., 2008). Using the clinically important LR scales enables a clinician to estimate the probability of the target condition being present. See Figure 1 for likelihood ratio scale of clinical importance and Table 2 for likelihood ratio interpretation guide.

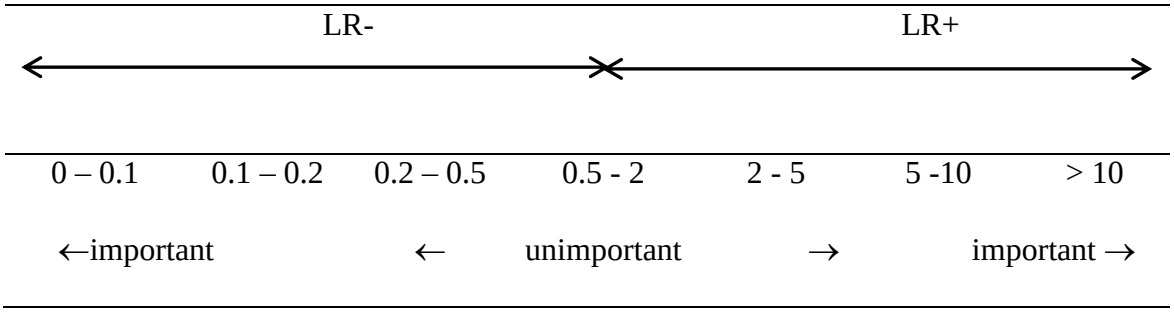

Figure 1. Likelihood Ratio Scale of Clinical Importance.
Adapted from Portney & Watkins (2009).

Table 2. Likelihood Ratio Interpretation Guide

LR-	Shift in Probability	LR+
< 0.1	large, conclusive	> 10
0.1 to 0.2	moderate, important	5 to 10
0.5 to 0.2	small, but sometimes important	2 to 5
0.5 to 1	very small, clinically irrelevant	1 to 2

Note. Adapted from C. E. Cook & Hegedus (2013), Glynn & Weisbach (2011), and Guyatt et al. (2008).

Probability estimation occurs pragmatically in the dynamic context of an individual patient case. For example, after taking a patient history, a clinician begins to formulate a preliminary working diagnosis. This hypothesized diagnosis can beformulate a preliminary working diagnosis. This hypothesized diagnosis can be confirmed or excluded through selective applications of diagnostic tests. Diagnostic test selection is usually based on clinical estimation of the patient's probability of having a target condition before an actual test result is known (referred to as pre-test probability) (Akobeng, 2007b). Pre-test probability of a target condition may be based on reported prevalence in literature, preliminary clinical exam findings, or a "best guess" based on clinical experience (heuristics) (Akobeng, 2007b; Portney & Watkins, 2009). By combining pre-test probability and the LR of a diagnostic test, a clinician can determine the post-test probability of a patient having the respective target condition. Specifically, a positive test result increases the post-test probability that the patient has the target condition while a negative test result implies the opposite. This relationship is expressed

through Bayes' theorem: post-test odds = pre-test odds x likelihood ratio (Akobeng, 2007b; Portney & Watkins, 2009). The mathematical calculation of Bayes' theorem has been simplified and represented in Fagan's nomogram to facilitate the use of LR in clinical practice. See Figure 2 for Fagan's nomogram.

In the case of continuous scale test results, the calculation of Sn and Sp can be determined from a receiver operating characteristic (ROC) curve (Akobeng, 2007c; Portney & Watkins, 2009). See Figure 3 for an example of an ROC Curve. An ROC curve is a graphic plot of the Sn and 1-Sp for continuous test values. The data point closest to the upper-left hand corner or at the inflection point of the curve of the ROC curve represents the best balance between true positive and false positive tests (Porney & Watkins, 2009). This data point may serve as a cutoff score for discriminating between individuals with and without the target condition. By determining a cutoff score, the diagnostic utility (e.g., Sn, Sp, LR+, LR-, and diagnostic odds ratio [DOR]) of test results can be calculated appropriately. ROC curves have three benefits in this respect: (a) determining a cutoff score for optimal Sn and Sp, (b) assessing the diagnostic utility of a test, and (c) comparing the usefulness of two or more combined tests (Akobeng, 2007c). It is important to recognize that ROC curves serve as a decision-making guide in balancing the Sn and Sp of a diagnostic test (Portney & Watkins, 2009).

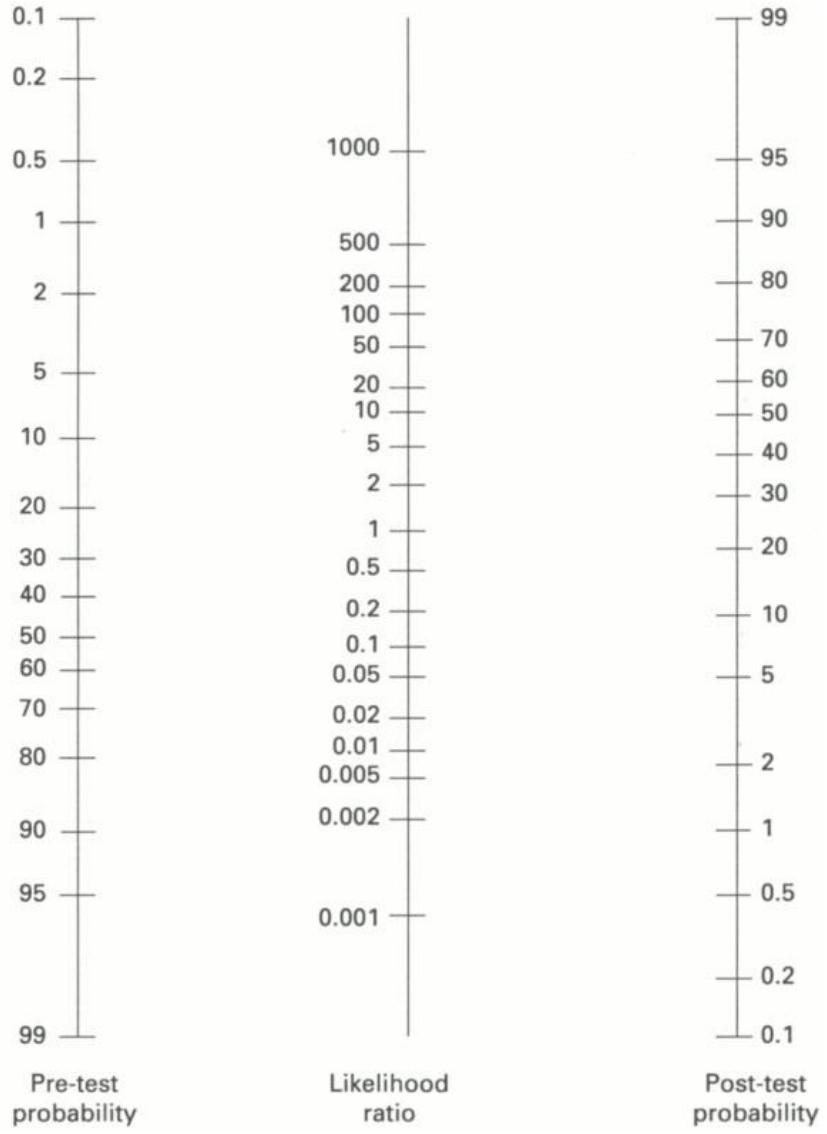

Figure 2. Fagan's Nomogram.
Taken from Glasziou (2001) and is an adaptation of Fagan's nomogram for Bayes' theorem (Fagan, 1975). The nomogram is used by drawing a straight line from the pre-test probability of the target condition through the likelihood ratio for the diagnostic test to the post-test probability.

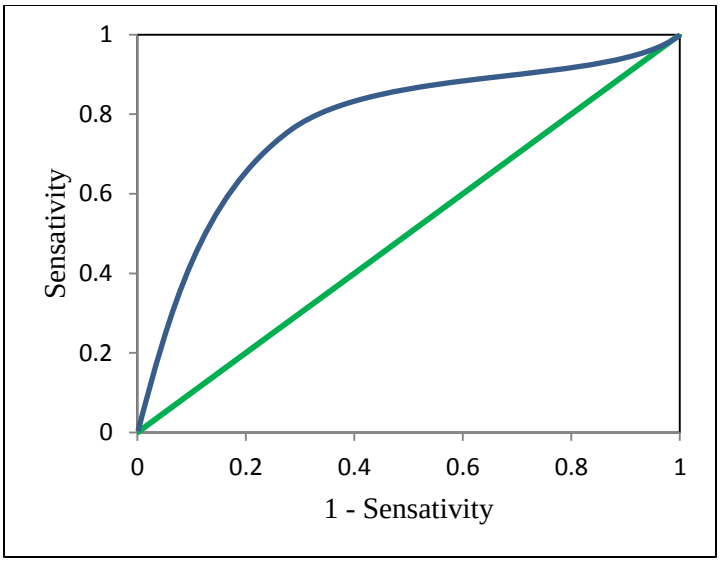

Figure 3. Typical Receiver Operating Characteristic (ROC) Curve.
The Y axis represents a diagnostic test's sensitivity; the X axis represents a diagnostics test's one minus specificity (1- specificity) x100; the diagonal center line represents a line of non-discrimination where the true positives and the false positives are equal; the graphed curve from the origin to the upper right hand corner represents test scores based on the relationship between the true positives and the false positives (Jewell, 2011; Portney & Watkins, 2009).

An optimal cutoff score may be moved subjectively to safeguard against false positive or false negative interpretive findings. This allows a clinician to use a test result as a screening tool to stratify a patient based on binary classification (e.g., high or low risk) for a target condition.

DOR may be used to summarize a diagnostic test's performance characteristics as a single number (Glas et al., 2003). DOR numerically describes how many times greater are the odds of a positive test result in a population with the target condition verses those without the target condition (CEBM, 2012); DOR = positive likelihood ratio/negative likelihood ratio = (sensitivity x specificity)/(1- sensitivity) x (1-specificity) (Glas et al.,

2003; Macaskill et al., 2010). DOR values may range from zero to infinity. Diagnostic tests with higher DOR values provide greater discrimination among individuals with and without the target condition. A DOR value ≤1 means that a diagnostic test does not have discriminatory power (Glas et al., 2003). Although a single number as an index of a diagnostic test's performance characteristics may seem beneficial, DOR are not appropriate for direct clinical application (CEBM, 2012). DOR typically are used in systematic reviews or meta-analyses but may be of value in comparing or ranking tests (Glas et al., 2003). Collectively, Sn, Sp, PPV, NPV, LR+, LR-, ROC curves, and DOR are advanced tools in EBP. Practitioners should have an understanding of the definitions and application of these Bayesian statistics to facilitate diagnostic and prognostic clinical decision making (Portney & Watkins, 2009).

However, in the scope of clinical practice, individual screening or diagnostic tools may not be sufficient to identify target conditions in complex patient conditions (Portney & Watkins, 2009). A combination or cluster of factors may be required to enhance diagnostic or prognostic utility beyond heuristics (Portney & Watkins, 2009). Greater clarity can be derived from employing more advanced methods to quantify the contributions of multiple variables (Norman & Streiner, 2008; Portney & Watkins, 2009; Steyerberg, 2010). CPMs are one viable approach to statistically cluster multiple factors and thus enhance diagnostic and prognostic utility (Glynn & Weisbach, 2011; Guyatt et al., 2008; Jewell, 2011; Portney & Watkins, 2009).

Clinical Prediction Models

CPMs are statistical models used to estimate probability related to screening, diagnosis, prognosis, or treatment interventions (Aronoff et al., 2010; Banks et al., 2010; Hicks et al., 2005; Jewell, 2011; Steyerberg, 2010). Clinically, CPMs are used to identify a cluster of predictors to support a diagnostic or prognostic assessment (Portney & Watkins, 2009). The range of predictive factors may include patient history, pathophysiology, symptomology, risk factors, test results, and outcome measures (Bainbridge et al., 2010; Banks et al., 2010). The advantage of clustering a set of factors in a CPM is to reduce the number of potential factors which strategically guide clinical decision-making when approaching complex patient cases (Brasher & Beattie, 2009; Bruce & Wilkerson, 2010a).

A broad range of CPMs exist in sports medicine to facilitate diagnostic and prognostic decisions (Glynn & Weisbach, 2011). The Ottawa Ankle Rule, for example, is a diagnostic CPM for determining the necessity of radiograph to rule out a fracture in the foot and ankle (Stiell et al., 1992). In orthopedic rehabilitation, prognostic CPMs have been developed for identifying treatment responsiveness for low back pain (Cai, Pua, & Lim, 2009; Hicks et al., 2005), neck pain (Cai et al., 2009), hip fractures (Steiner, Kramer, Eilertsen, & Kowalsky, 1997), spinal manipulation (Childs et al., 2004; Fritz, Childs, & Flynn, 2005), and hip osteoarthritis (A. A. Wright, Cook, Baxter, Dockerty, & Abbott, 2011; A. A. Wright, Cook, Baxter, Garcia, & Abbott, 2010; A. A. Wright, Cook, Flynn, Baxter, & Abbott, 2011). More recently, CPMs are being developed in athletic populations to identify modifiable risk factors that can be addressed through targeted

injury prevention strategies (Bruce & Wilkerson, 2010a, 2010b; Wilkerson, Giles, & Seibel, 2012; Wilkerson, 2010).

The methodological approach to designing CPMs exists along a spectrum of quality, validity, and clinical utility (Glynn & Weisbach, 2011; Steyerberg, 2010). It is important to recognize the multiphase approach to establishing a CPM. CPM development has been defined as a three phase process: (a) derivation, (b) validation, and (c) impact analysis (Childs et al., 2004; McGinn et al., 2000) or recalibration of the model (Steyerberg, 2010). The combination of the research design and degree of development defines a hierarchy of evidence for evaluating CPMs (Portney & Watkins, 2009).

The first phase in constructing a CPM is the derivation stage. The derivation phase is characterized by identifying a set of preliminary factors related to a specific outcome (Portney & Watkins, 2009). The preliminary factors may be generated from a combination of methods such as expert opinion, review of literature, prior research, and clinical practice (Childs et al., 2004). Derivation models are typically constructed in a select cohort without a comparison or control group (Glynn & Weisbach, 2011). Single center retrospective cohort design is one of the primary means to initiate the development process for a CPM without the constraints of a randomized controlled longitudinal prospective study (Steyerberg, 2010). The derivation process is important in determining whether a small set of factors may predict an outcome prior to investing in longitudinal prospective validation research designs. Subsequently, derivation models need further development before being applied clinically (Portney & Watkins, 2009). For this reason,

the hierarchy of evidence for prediction models categorizes derivation of CPMs as level IV (lowest quality) on the continuum of evidence (Portney & Watkins, 2009). Validation is the second stage in developing a CPM. This stage is a critical step in authenticating predictor variables in a new cohort (Glynn & Weisbach, 2011). The validation process encompasses an extensive range of methodological approaches (Steyerberg, 2010); see Table 3. Practically, the approach to validating CPMs occurs in prospective cohorts or randomized controlled trials (Glynn & Weisbach, 2011). When validated in small prospective samples, CPMs are classified as level III on the hierarchy of evidence for prediction models. Table 4 provides an overview of the hierarchy of evidence for evaluating CPMs. Such CPMs can be applied only in similar patient groups and may have limited clinical application (Portney & Watkins, 2009). Level II CPMs have been validated in a broader spectrum of patients or multiple settings, have demonstrated accuracy, and have been found appropriate for clinical application (Portney & Watkins, 2009).

Table 3. Methodological Approaches for CPM Validation

Large scale retrospective[a]
New cohort of clinicians[b]
New patient sample[b]
Prospective cohort[b]
Cohort study for prognosis[a]
One narrow prospective sample[c]
Case-control[a]
Case-series[a]
Nested case-control[a]
Cross-sectional[a]
Multiple small center prospective sample[c]
One center large broad spectrum prospective sample of new patients[c]
One center large broad spectrum prospective sample of new clinicians[c]
One center large broad spectrum prospective sample of new patients and clinicians[c]
Randomized clinical trial[b]
Multivariate modeling[a]
Predictors and outcomes modeling[a]

Note. [a] Steyerberg (2010). [b] Glynn & Weisbach (2011). [c] Guyatt et al. (2008).

Table 4. Hierarchy of Evidence for CPMs

Level	Type of Evidence	Clinical Application
I	Model has been validated in a large prospective patient population AND one impact analysis study has been performed demonstrating improved outcomes and/or benefit.	Model can be accurately used to change clinician behavior or patient outcomes in a wide spectrum of clinical settings.
II	Model has been validated in a large scale prospective study with a broad spectrum of patients and/or clinicians OR the model has been validated in multiple diverse setting.	Model can be accurately used in a wide spectrum of clinical settings.
II	Prospectively validated in narrow sample.	Model may only be applied in patient populations similar to study's prospective sample.
IV	Preliminary or derivation models based on retrospective design, statistical modeling, or single center split sample.	Model needs to be validated before being generalized beyond sample; lacks clinical utility.

Note. Adapted from Portney & Watkins (2009).

The third phase in developing CPMs relates to impact analysis (Childs & Cleland, 2006; Glynn & Weisbach, 2011; Guyatt et al., 2008; Portney & Watkins, 2009) or model recalibration (Steyerberg, 2010). Impact analysis is intended to determine how a CPM influences clinical practice specific to changed behavior, modified decision making, or improved outcomes (Guyatt et al., 2008). Recalibration refers to a process of adjusting a predictive model based on how a CPM performs clinically. Advances in diagnostic procedures, changes in patient populations, changes in treatment strategies, or other factors may influence the characteristics of a CPM and necessitate recalibration or versioning of predictor or outcome variables (Glynn & Weisbach, 2011; Steyerberg, 2010). The concepts of impact analysis and recalibration are variations of validation procedures and entail prospective research design. CPMs that use validation based on impact analysis or recalibration are classified as Level I on the hierarchy of evidence for prediction models (Portney & Watkins, 2009).

CPMs are commonly used in sports medicine (Glynn & Weisbach, 2011) and are applicable to athletic training practice. As a decision-making tool, CPMs have potential to assist in diagnosis, prognosis, and treatment strategies. This is particularly relevant in the context of complex patient groups or injury patterns encountered in clinical practice. Collegiate baseball players are one such specialized patient group and often present with complex UE injury patterns. The diagnosis, prognosis, and treatment of UE SRI in collegiate baseball players is complex. Consequently, there is a need to improve the decision-making process to assist clinicians in improving patient outcomes. A CPM of

UE SRI would be an important advancement in assisting clinicians in navigating the complexities of this patient population.

We have been unable to locate a CPM specific to UE SRI in baseball in the present literature. However, a prospective derivation prediction model for UE overuse injury in Division I softball players (n = 35) has been described (Bruce & Wilkerson, 2010b). Although softball and baseball are both UE throwing sports, the mechanics of underhand windmill pitching (Oliver, Plummer, & Keeley, 2011; Werner et al., 2005; Werner, Jones, Guido, & Brunet, 2006) and overhand pitching (Fleisig et al., 1996) motions are distinctly different. Furthermore, the epidemiologies associated with collegiate softball and baseball injuries are distinctly different (Dick et al., 2007; Marshall, Hamstra-Wright, Dick, Grove, & Agel, 2007). Collectively this indicates that the prediction model specific to collegiate softball should not be applied to collegiate baseball; thus there remains a need for development of a CPM for UE SRI in baseball.

Predictive Factors of a Preliminary CPM

As stated earlier, generating a list of predictive factors related to a specified outcome parameter is the initial step in creating a CPM (Childs et al., 2004). A well-constructed CPM is predicated on predictor factors having a strong relationship with the outcome measure (Glynn & Weisbach, 2011; Steyerberg, 2010). The rationale for selecting predictor factors should be supported through review of literature, expert opinion, or a conceptual framework (GH Guyatt, Bombardier, & Tugwell, 1986; Streiner & Norman, 2008). The task of identifying potential predictor factors in a derivation stage of model development may stem from expert brainstorming (Childs et al., 2004) or a

pragmatic approach of choosing available factors present in clinical practice (Steyerberg, 2010). A researcher must review available data and make judgments on the feasibility of potential factors (Streiner & Norman, 2008). In the context of a single-center retrospective cohort design, the availability and completeness of predictors may be limited to available data (Steyerberg, 2010). Predictor factors collected clinically often include demographics, patient history, comorbidity(s), physical exam findings, self-report measures of health status and quality of life, basic laboratory tests, or physical functional status (Beattie & Nelson, 2006; Falk & Fahey, 2009; Glynn & Weisbach, 2011; McGinn et al., 2000; Steyerberg, 2010).

A broad range of risk factors has been identified and suggested as causal for UE SRI in baseball athletes. These risk factors include: muscle strength deficits (Brown et al., 1988; Yildiz et al., 2006), muscle fatigue (Mullaney et al., 2005), internal and external strength imbalance (Lewis & Valentine, 2007), glenohumeral internal rotation deficit (GIRD) (Borsa et al., 2006; Dines et al., 2009; Wilk et al., 2010), scapula dyskinesis (Cooper et al., 2002; Kibler & McMullen, 2003), maximum pitch velocity (Bushnell et al., 2010), pitching volume (Fleisig et al., 2010; Olsen et al., 2006), pitch type (e.g. slider , curveball) (Escamilla et al., 1998; Fleisig et al., 2010; Fleisig et al., 2006), playing position (Fleisig et al., 2010; Olsen et al., 2006), throwing biomechanics (Fleisig et al., 1995; Fleisig et al., 1996), and low self-reported functional assessment measures (Alberta et al., 2010; Domb et al., 2010; Neuman et al., 2011). These risk factors can be conceptually categorized into three areas: (a) self-reported outcome scores, (b) sport performance factors, and (c) FPMs.

Self-Reported Outcome Measures

Self-reported outcome measures are a branch of a broader field related to health measurement scales (Streiner & Norman, 2008). Health measurement scales originated as a means to quantify psychometric parameters in the social sciences (DeVellis, 2003). The use of health measurement scales is well represented in a broad spectrum of sports medicine literature (Suk, Hanson, Norvell, & Helfet, 2009) and clinical practice settings (Streiner & Norman, 2008). Health measurement scales traditionally have been classified under one of the following: (a) general health, (b) disease specific pathology, (c) regional specific, (d) dimension specific, and (e) summary items (Valovich McLeod et al., 2008; R. W. Wright & Baumgarten, 2010). The selection of a particular health measurement scale should appropriately match the patient population or presenting medical condition (Streiner & Norman, 2008; Suk et al., 2009).

Within orthopedic medicine, between 30 and 50 musculoskeletal outcome measures and instruments related to the shoulder have been reported (Suk et al., 2009; R. W. Wright & Baumgarten, 2010). Wright and Baumgartner (2010) identified ten shoulder outcome measures appropriate for clinical practice (see Table 5 - Common Shoulder Outcome Measures, for an overview). Despite the number of available UE specific outcome measures, no validated self-report instrument to measure functional status of the upper extremity in the overhead athlete was reported until recently (Alberta et al., 2010; Domb et al., 2010; Neri, ElAttrache, Owsley, Mohr, & Yocum, 2010; Neuman et al., 2011; Sauers et al., 2011; Sauers, Thigpen, Huxel, & Bay, 2009).

Table 5. Common Self-Reported Shoulder Outcome Measures

Study	Shoulder Outcome Measure	Primary Validation	Sport Related Items[a]	Scope of Baseball Related item
Michener et al., (2002)	American Shoulder and Elbow Surgeons (ASES) Standardized Shoulder Assessment Form	Middle aged males	2 (10)	Throw a ball overhand; do usual sports
Constant & Murley, (1987)	Constant	Middle aged males	1 (8)	Recreation/sport
Hudak, et al., (1996)	Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire	General population; middle aged	4 (34)	Sports and performing arts module
Alberta et al. (2010)	Kerlan-Jobe Orthopaedic Clinic overhead athlete shoulder and elbow score (KJOC-SES)	Collegiate overhead athletes,	10 (10)	Sport specific
Dawson et al. (1999)	Oxford Shoulder Instability Score	Individuals with SH instability	1 (12)	Sporting activities & hobbies
Beaton et al. (2005)	Quick DASH	General population; middle aged	4 (15)	Sports and performing arts module
Hollinshead et al. (2000)	Rotator Cuff Quality-of-Life	General population; middle aged	4 (34)	Recreational activity and sport participation module
Brophy et al. (2005)	Shoulder Activity Level	General population; middle aged	0	n/a

Table 5 (continued)

Williams et al. (1999)	Single Assessment Numeric Evaluation (SANE)	Patients who underwent SH surgery for impingement or AC separation	0	n/a
Ellman et al. (1986)	UCLA Shoulder Score	General population, middle aged	0	n/a
Kirkley et al. (1998).	Western Ontario Instability Index (WOSI)	General population; middle aged	4 (21)	Sport, recreation, and work module
Lo et al. (2001)	Western Ontario Osteoarthritis of the Shoulder (WOOS) Index	General population; middle aged	4 (19)	Sport, recreation, and work module

Note. Adapted from Suk et al. (2009) and R. W. Wright & Baumgarten (2010).
[a]Number of sport specific items (total number of items).

The Kerlan-Jobe Orthopaedic Clinic overhead athlete shoulder and elbow score (KJOC-SES) (Alberta et al., 2010) and the Functional Arm Scale for Throwers© (FAST©) (Sauers, Ellery, Snyder, & Bay, 2008; Sauers et al., 2009) are self-report instruments developed specifically to measure functional status of the shoulder and elbow in overhead athletes. Existing self-report outcome instruments such as the Disabilities of the Arm, Shoulder and Hand (DASH) and American Shoulder and Elbow Surgeons (ASES) Standardized Shoulder Assessment Form) are limited in their ability to evaluate functional outcomes (Alberta et al., 2010) or health related quality of life (HRQOL) (Sauers et al., 2011) in overhead athletes. The DASH and ASES instruments do not have items to measure overhead function specific to game and practice conditions. Furthermore, the common shoulder outcome measures do DASH and ASES instruments do not have items to measure overhead function specific to game and practice conditions. Furthermore, the common shoulder outcome measures do not discriminate among sporting activities, recreation, and work. Subsequently, the KJOC-SES and FAST© were developed to provide valid and responsive self-report outcome measures specific to the high demands of overhead athlete populations (Alberta et al., 2010; Sauers et al., 2008).

The KJOC-SES has demonstrated a high correlation to existing shoulder outcome measures like the DASH and the ASES, but provides the advantage of correctly stratifying functional status in overhead athletes based on UE SRI history (Alberta et al., 2010) whereas the others do not. Since its development, the KJOC-SES has been validated in subgroups of baseball players who are asymptomatic (Kraeutler et al., 2012), have undergone ulnar collateral ligamnet (UCL) recontruction (Domb et al., 2010), type

II superior labral anterior-posterior (SLAP) lesion repairs (Neri et al., 2010; Neuman et al., 2011), capsular plication for anterior shoulder instability (Hsu, Gould, Fonseca-Sabune, & Hausman, 2009), or present with medial elbow pain (Sweitzer et al., 2012). The KJOC-SES is reported to be a more sensitive and accurate outcome measure compared to the DASH and the ASES in discriminating changes in functional status in collegiate overhand athletes (Alberta et al., 2010; Neuman et al., 2011)

In addition to the KJOC-SES, an alternative self-reported outcome measure specific to throwing athletes has recently been reported (Sauers et al., 2011). Functional Arm Scale for Throwers© (FAST©) is a single self-report measure designed to measure health-related quality of life (HRQOL) based on the five disablement domains: pain, impairment, functional limitation, disability, and societal limitation. The FAST© instrument was validated in a cohort of adolescent pitchers (n = 21) and was found to better discriminate between those with and without positive pain and histories of UE SRI compared to the DASH (Sauers et al., 2009). Subsequently, FAST© has been validated as a regional specific self-report measure in a cohort (n = 25) high school and college softball pitchers (Sauers et al., 2011). It should be noted that FAST© is a copyright-protected instrument and to date has not been made available through the literature or public domain.

Incorporating a self-report scale such as the KJOC-SES into clinical research is consistent with the EBP because these scales provide patient-specific assessment of functional (Reiman & Manske, 2011). It is important to recognize that self-reported outcome measures are not intended to be used in isolation but are part of a

comprehensive approach to patient management. Obtaining a more comprehensive clinical picture needs to include a broad spectrum of information to quantify the impairment, functional limitations, and disability domains. In this respect, self-report measures can be coupled with sport performance risk factors and FPMs to develop a more comprehensive understanding of the relationship between SRI and disablement in high functioning athletic populations. To date there are no known investigations of injury risk which incorporate self-reported outcome measures in combination with other risk factors in baseball players.

Sport Performance Risk Factors

An understanding of injury causation has been suggested to be a cornerstone of SRI prevention (Bahr & Krosshaug, 2005). Identifying risk factors, which may predispose an athlete to SRI, can be delineated as intrinsic (e.g., age, gender, anatomy) or extrinsic (e.g., injury exposure rates, environmental conditions, sport performance variables) (Bahr & Krosshaug, 2005). A range of baseball performance extrinsic injury risk factors have been presented (Bradbury & Forman, 2012; Bushnell et al., 2010; Fleisig et al., 2010; Olsen et al., 2006). Baseball injury risk factors commonly have been reduced in clinical terms to a nebulous collection of issues such as mechanical flaws, excessive pitching, improper strength and conditioning, or improper rest (Ortiz, 2011). Reducing these risk factors into broad categories (such as mechanical flaws, and pitching volume, strength deficits) without quantified descriptors provides little clarity in furthering understanding the relationship between risk factors and UE SRI. Fortunately, evidence has begun to emerge that identifies specific risk factors for shoulder and elbow

injuries in baseball players (Bradbury & Forman, 2012; Bushnell et al., 2010; Fleisig et al., 2010; Olsen et al., 2006). Understanding this literature is paramount to developing a comprehensive CPM for UE SRI in baseball athletes.

Maximum pitch velocity has been identified anecdotally (Ortiz, 2011) and prospectively as a risk factor for elbow injury in professional (Bushnell et al., 2010) and for shoulder and elbow injuries in adolescent baseball pitchers (Olsen et al., 2006). Anecdotal data have been used to indicate that maximum pitch velocities over 100 mph are a risk factor for injury in professional baseball players (Ortiz, 2011). However, these data have not been substantiated in the literature. The work of Bushnell et al. (2010) in a small prospective cohort (n = 23) has been instrumental in describing the association between maximum pitch velocity and ulnar collateral ligament injury. High average pitch velocity of 39.88 m/s (89.22 mph) versus low average pitch velocity 38.09 m/s (85.22 mph) has been associated with an increased risk of ulnar collateral ligament sprain (Bushnell et al., 2010). The relationship between maximum pitch velocity and risk of injury is independent of pitching role (starter versus reliever), games played, innings pitched, total pitches thrown, or pitches per game (Bushnell et al., 2010). A relationship may exist among the length of playing career, maximum pitch velocity, and UCL injury (Bushnell et al., 2010). In adolescent aged pitchers, average fastball velocity above 85 mph has been established as the threshold for increasing injury risk (Olsen et al., 2006). It is important to note that the use of maximal or average pitch velocity as a risk factor has not been established in high school, or collegiate pitchers. Incorporating maximum or average pitch velocity as a predictive factor thus warrants consideration.

An ROC curve from the Bushnell et al. (2010) data set yields an average velocity of 84 mph that may serve as a velocity threshold for increased risk of UE SI. Hand tabulation of a 2x2 contingency table with UCL injury as a reference standard and pitch velocity dichotomized as high velocity (> 84 mph) and low velocity (≤ 83.9) yields an Sn of 0.46, Sp of 0.75, LH+ 1.86 of and LH- 0.71. This indicates that pitch velocity as a single risk factor lacks clinical utility in predicting injury despite the reported statistical relationship between pitching velocity and UCL injury. This may be an initial step in establishing velocity as a risk factor; however, the Bushnell et al. (2010) sample size (n = 23) may limit generalization.

Pitch type also has commonly been identified as a risk factor for injury (Andrews & Fleisig, 1998). The curveball was believed to increase risk of shoulder pain by 52% while the slider has been associated with an 86% increased risk of elbow pain (Lyman, Fleisig, Andrews, & Osinski, 2002). Recent longitudinal prospective analysis has refuted the notion that breaking pitches in youth baseball players correlate with shoulder or elbow injuries (Fleisig et al., 2010). This evidence has been substantiated by biomechanical analysis that indicates that curveballs do not produce greater kinetic force in the shoulder or elbow in collegiate pitchers (Barrentine, Matsuo, Escamilla, Fleisig, & Andrews, 1998; Fleisig et al., 2006). Evidence has not correlated the slider with an increased prevalence of injury; however, the pitch produces greater joint torques compared to the fastball in mature pitchers (Escamilla et al., 1998). This evidence collectively suggests that pitch type may not be a definitive risk factor of UE SRI in baseball pitchers.

Pitching volume is another proposed risk factor for UE SRI in youth (Fleisig et al., 2010) and professional pitchers (Bradbury & Forman, 2012). An increased pitching volume in youth has been correlated with an increased risk for shoulder and elbow injury with a suggested threshold of 100+ innings per season (Fleisig et al., 2010). Pitching volume thresholds have not been specified for high school, collegiate, or professional levels. Recently, cumulative pitching load in combination with decreased rest days has been quantified as a negative factor in pitching performance and hypothesized as a potential risk factor for UE SRI in professional baseball pitchers (Bradbury & Forman, 2012). Bradbury and Forman (2010) suggest that the negative impact of high pitching volume may be more likely correlated with a decline in pitching performance (e.g., ERA, strike-to-balls ratio, homeruns) versus UE SRI rate. Additionally, extended pitch counts of 150 pitches per game have been found to adversely affect shoulder kinematics, which may predispose a collegiate player to increased risk of injury (Kohlmeyer, 2005). A pitch count of 70 pitches per game has been suggested as the threshold for producing significant differences in pitching mechanics (Kohlmeyer, 2005); however, a correlation with UE SRI has not been established based on this finding. Collectively, although the exact statistical relationship between pitching volume and UE SRI has not been clearly established in skeletally mature pitchers, such data warrant further consideration.

In addition to pitch counts, throwing volume by position has been described in collegiate baseball players (Barrett & Burton, 2002). The number of active (direct game play) and inactive (unrelated to direct game play) throws contributes to the collective throwing volume sustained in the context game play. The frequency of observed game

play throws by position were reported as follows: pitchers 51%, catchers 29%, infielders 17% and outfielders 3% (Barrett & Burton, 2002). These data indicate that throwing volume is position specific and that game play throwing volume in combination with pitch count predisposes pitchers and catchers to the highest volume of arm related throwing stress. This would account for the increased prevalence of UE SRI specifically in pitchers (Dick et al., 2007; Fleisig et al., 1995; Posner et al., 2011). Furthermore, throwing volume by position also accounts for the increased injury rates in multiple position players who participate as a starting pitcher and catcher in the same game (Fleisig et al., 2010). The relationship between game-day throwing volume and playing position is a risk factor for UE SRI in lower levels of baseball and may be a risk factor for multiple-position collegiate players.

Level of experience has been suggested as another risk factor for UE SRI (Chambless, Knudtson, Eck, & Covington, 2000). Rookie professional baseball players sustain a significantly higher injury rate than more experiences players. The higher injury rates are attributed to participating at a high level of play without sufficient time to condition and adapt to longer playing seasons and higher competitive demands. It can be posited that a similar relationship may exist when athletes transition from little league to high school and from high school to college.

Collectively, sports performance risk factors can be grouped into five distinct categories: (a) game-play exposure, (b) average fastball velocity (pitcher specific), (c) throwing volume (pitcher specific), (d) playing experience, and (e) playing position (pitcher versus fielder). Although progress has been made in clarifying sport

performance risk factors in adolescent baseball players, additional investigation is needed to understand the multifactorial nature of risk factors in relationship to UE SRI in baseball. The influence of these sport performance risk factor categories has not been fully considered in collegiate and professional baseball players. One could suggest that these sport performance factors are important in understanding the risk for UE SRI in more advanced levels of baseball competition; however, the magnitude of these risk factor categories warrants further study.

Recently, advancements have been made in understanding the risk factors for UE SRI in adolescent baseball pitchers. A 10-year prospective investigation by Fleisig et al. (2011) identified a number of important risk factors for serious UE SRI in youth baseball pitchers. Although the investigation is a landmark study, the investigators did not present a multifactorial analysis of risk factors nor describe a CPM. Olsen et al. (2006) prospectively developed multivariate logistic regression models of risk factors in adolescent baseball pitchers. The model identifies four factors associated with SRI: (a) pitching more than eight months, (b) pitching more than 80 pitchers per game, (c) fastball velocity greater than 85 mph, and (d) pitching with arm fatigue (Olsen et al., 2006). Despite identifying multiple factors, the model of Olsen et al. (2006) included only single-factor statistical analysis and failed to present a single multifactorial model to account for a composite of risk factors. A CPM that identifies a composite of risk factors may further our understanding of athletes at risk for significant UE SRI.

Functional Performance Measures

FPMs are physical testing procedures used for the assessment of physical abilities (Reiman & Manske, 2011). Function can be measured through impairment measures (e.g., manual muscle testing, joint range of motion), self-report measures (e.g., pain scales, DASH, KJOC-SES), and physical performance measures (e.g., muscle endurance testing, dynamic balance, jump/hop testing) (Reiman & Manske, 2011). Reiman and Manske (2009) have cataloged approximately 140 individual FPMs which span 10 parameters: anthropometric; muscle length; fundamental movements; balance; aerobic; strength and power; speed, agility, and quickness; trunk; upper extremity; and lower extremity (Reiman & Manske, 2009). Because of the large number of available tests, the inclusion of specific FPMs in clinical practice may be confusing for clinicians. In an effort to simplify screening procedures, clusters of tests have been grouped to form batteries to quantify the characteristics of function, injury assessment, sport performance, and injury prediction in athletic populations (Butler, Plisky, Southers, Scoma, & Kiesel, 2011; G. Cook et al., 2006a, 2006b; G. Cook et al., 2010; Frohm, Heijne, Kowalski, Svensson, & Myklebust, 2011; Kiesel, Plisky, & Butler, 2009; Kiesel et al., 2007; Minick et al., 2010; Plisky et al., 2009; Plisky, Rauh, Kaminski, & Underwood, 2006; Schneiders, Davidsson, Horman, & Sullivan, 2011). Using a battery of tests allows for a standardized approach to the assessment of function to aid clinical practice and to facilitate the long-term study of the reliability and validity of FPMs (Reiman & Manske, 2011).

Individual FPMs traditionally have been classified by discrete physical parameters (e.g., balance, strength, power) and/or regional designation (lower-extremity, trunk, upper-extremity) (Reiman & Manske, 2009). More recently a FPMs twelve-level classification hierarchy has been proposed to define the assessment levels of function (Reiman & Manske, 2011), see Table 6.

Table 6. Classification Hierarchy for the Assessment of Function in Individuals

Level	Description of primary assessment
I	Subjective report (patient or clinician)
II	Impairment
III	Static observation, posture, balance
IV	Dynamic posture, general movement patterns, single plane dynamic balance
V	Movement patterns encountered during high level tasks and/or multi-planar dynamic balance
VI	Specific movement patterns
VII	Performance-based measures predominantly in one plane
VIII	Performance-based measures predominantly in one plane, requiring limited base of support, multiple joints, multiple muscle groups, or explosive movements
IX	Performance-based measures predominantly in multiple planes and/or requiring explosive movement
X	Performance-based measures predominantly in multiple planes and/or requiring explosive movement with the quality of performance assessed
XI	Replication of specific tasks performed during individual sports/occupational activity or clusters of performance-based measures that replicate sports/occupational activity
XII	Cumulative assessment including performance assessment with self-report and bi-psycho-social measures

Note. Adapted from Reiman & Maske (2011)

FPMs exist on a continuum which may use impairment-based measures (e.g., range of motion, manual muscle testing, gait), self-report measures, and physical performance measures (e.g., muscle endurance tests, movement patterns). Impairment-based and

observation-based (e.g., static posture) assessments of function are classified as lower level while multi-plane (e.g., figure-8 hop) or explosive movements (e.g., triple hop for distance) are classified as higher level functional assessments. In general, the closer an FPM approximates an actual sport, occupational, or daily activity the higher the respective classification rating (Reiman & Manske, 2011). Reiman and Manske (2011) suggest that function should be assessed along a continuum and include multiple measures. An optimal approach for functional assessment in athletic populations should incorporate a range of physical parameters and a balance of regional designations across several assessment levels. Such an approach would necessitate transitioning from individual tests to a cluster of FPMs to obtain a
global assessment and a high level of classification.

FPMs have been clustered to form a battery of tests that incorporate multiple discrete parameters and regional designations to derive a global assessment measure of function (G. Cook et al., 2006a, 2006b; Frohm et al., 2011; Hegedus, 2011; Kiesel et al., 2009). The most noted FPM batteries are the Functional Movement Screen™ (FMS™) (G. Cook et al., 2010) and Frohm's nine-test screening battery for athletes (Frohm et al., 2011). Recently an alternative global battery of tests, the Targeted Enhanced Athletic Movement Screen (TEAM-S) has been developed for athletic populations (Hegedus, 2011). An overview or comparison of the FMS™, Frohm's nine-test screening battery, and TEAM-S is provided in Table 7.

Table 7. Comparison of Functional Performance Screening Batteries

Performance Measure	FMS® (21 pts)	FROHM 9-Test Screen (27 pts)	TEAM-S (75 pts)
Beighton Hypermobility			Yes
Full Squat	Yes	Yes	Yes
Single Leg Squat		Yes	Yes
Downward Dog			Yes
Active Straight Leg Raise	Yes	Yes	Yes
Shoulder Mobility Test		Yes	Yes
Y-Balance for upper-extremity			Yes
CKCuest			Yes
Side Plank Hip Abduction			Yes
Side Plank Hip Adduction			Yes
Nordic Hamstring Test			Yes
Triple Hop for Distance			Yes
Vertical Leap			Yes
In-line Lunge for Distance	Yes	Yes	Yes
Lateral Lung for Distance			Yes
Qualitative Dyskinesis Screening Test[a]			Yes
Push-up Test	Yes	Yes	
Diagonal Lift Test		Yes	
Straight Leg Raise Test (Passive)		Yes	
Rotary Stability	Yes	Yes	
Hurdle Sep	Yes		

Note. [a]The Qualitative Dyskinesis Screening Test is not part of the original TEAM-S battery of tests and was added for UE athletes.

FPMs batteries integrate a variety of measures in an attempt to capture an envelope of function central to active populations This is an important consideration in determining the relationship between functional or athletic performance and injury risk (Reiman & Manske, 2011).

The FMS™ is a commercialized functional assessment system comprised of a seven item battery intended to identify functional imbalances thought to affect performance and prevent injury (G. Cook et al., 2010). The maximum score for the FMS™ is 21 points. Each individual FPM item is subjectively scored on a 4-point scale (0-1-2-3): 0 if pain present; 1 = movement pattern is incomplete or not performed consistent with the FMS™ definition; 2 = movement pattern demonstrates compensation, faulty form, or loss of alignment consistent with the FMS™ definition; 3 = movement pattern is complete and consistent with FMS™ definition (G. Cook et al., 2010). It is important to note that the original text describing the FMS™ did not report reliability or validity despite claims of its clinical utility for improving performance and injuryvalidity despite claims of its clinical utility for improving performance and injury prevention (G. Cook et al., 2010). Recent studies have reported normative values of the FMS™ in young active populations (15.7, 95% CI [15.4-15.9]) (Schneiders et al., 2011), professional football athletes (16.9±3.0) (Kiesel et al., 2007), and active military service members (15.7±0.2) (Teyhen et al., 2012). Individual item reliability (kappa) has been reported to range from 0.73 to 1.00 (Schneiders et al., 2011), while total score reliability (ICC) has ranged from 0.74 (Teyhen et al., 2012) to 0.92 (Minick et al., 2010).

The validity of the FMS™ to predict injury is disputed. Kiesel et al. (2007) reported a cutoff score equal to or less than 14 was predictive of serious injury (Sp of 0.91, Sn of 0.54, LR+ of 5.92, and a LR- of 0.51) in a cohort (n = 46) of professional football players. Based on these original data, a cutoff score of 14 correctly identified 53.8% (7 of 13) of the injury cases. In contrast, Teyhen et al. (2012) reported that an FMS™ cutoff score of ≤ 14 identified correctly only 15.6% of the injury cases in a cohort (n = 64) of active military service members. The discrepancy in correctly identifying injury calls into question the validity of the FMS™ as a viable screening tool and highlights the need for additional and larger longitudinal investigations to determine the screen's psychometric properties (Teyhen et al., 2012).

The Frohm nine-test screening battery was developed over a 5 to 10-year period of clinical practice by selectively combining items from the FMS™ and the United States Tennis Association High-Performance Profile screening system (Frohm et al., 2011). Each test item is subjectively scored on a four point scale (0-1-2-3); 0 if pain is present; 1 = not correct despite compensatory movement; 2 = correct but with compensatory movement; 3 = correct without compensatory movement. The normative composite score in healthy elite male soccer athletes was established between 18.3 (95%CI [14.9-21.7]) and 18.0 (95%CI [14.4-21.7]) with a test-retest reliability of ICC of 0.81 to 0.80 (Frohm et al., 2011). Normative and reliability values were based on a small cohort (n = 26) of healthy elite level male soccer players (Frohm et al., 2011) and may not be generalized to other populations. Frohm et al. (2011) suggested that the screening battery may be limited in clinical utility because it has not been validated for injury prevention,

rehabilitation, or performance enhancement. Aside from the original investigation, we were unable to locate other references of the Frohm nine-test screening battery in the literature.

Hegedus (2011) developed and proposed the TEAM-S as an alternative to the commercialization of a functional performance screening system and to develop a screening battery consistent with EBP. The individual test items that comprise the TEAM-S originally were selected based on 20 years of physical therapy clinical experience with functional performance screening in a broad spectrum of healthy and injured recreational, high school, collegiate, and professional athletes (E. J. Hegedus, personal communication). Individual TEAM-S items were selected based on providing a mixture of upper-extremity, trunk, and lower-extremity functional measures to reflect a composite of functional screens related to sports activity. Most importantly, individual TEAM-S items have established reliability measures reported in the literature; see Table 8. Each TEAM-S item is scored on a 6 point rating scale (0-1-2-3-4-5) with a maximum score of 75 points. Unlike the FMS^{TM} or the Frohm nine-test screen, the scoring of a TEAM-S item is based upon a combination of subjective scoring criteria and objective measurements. Appendix B is the TEAM-S score sheet and provides a description of each test and its respective scoring criteria. The psychometric properties of the TEAM-S are currently under investigation in an international multicenter research project. The global reliability and validity of TEAM-S and has not been reported in literature.

Table 8. TEAM-S Functional Performance Measures Including Assessment Level and Previously Reported Reliability

Functional Performance Measures	**Assessment Level[1]**	**Reliability**
Beighton Hypermobility	II	ICC = 0.98-0.96 [8]
Full Squat	VII	Inter, k_w = 0.68, Intra, k_w = 0.76 [4] Inter ICC = 0.73 [10]
Single Leg Squat	VII	Inter, k = 0.8-0.6, Intra, k = 0.8-0.613 [2] Inter, k = 0.99, Intra, k = 0.98-0.88 [7] Inter ICC = 0.53 [10]
Downward Dog	III	none reported
Active Straight Leg Raise	II	Inter, k_w = 0.69. Intra, k_w = 0.60 [4] ICC = 0.94-0.99 [6] Inter ICC = 0.64 [10]
Shoulder Mobility Test	II	Inter, k_w = 0.73, Intra, k_w = 0.68 [4] Inter ICC = 0.85 [10]
Y-Balance for upper-extremity	VIII	Test-retest ICC = 0.99 -0.80, Inter ICC = 1.00 [12]
CKCuest	VIII	ICC = 0.99 [11]
Side Plank Hip Abduction	VII	Inter, ICC = 0.70 – 0.59, Intra, ICC = 0.74[3]
Side Plank Hip Adduction	VII	none reported
Nordic Hamstring Test	VII	Inter, k = 0.24 [15]
Triple Hop for Distance	IX	ICC = 0.97 [13]
Vertical Leap	VIII	Males, ICC = 0.94, Females, ICC = 0.87-0.89 [5]
In-line Lunge for Distance	VII	Inter, k_w = 0.45, Intra, k_w = 0.69 [4] Inter ICC = 0.75 [10] Intra ICC = 0.96 [13]
Lateral Lung for Distance	VII	Intra ICC = 0.96 [14]
Qualitative Dyskinesis*	VII	k_w = .061-0.48

Note. ICC = Interclass correlation; K = kappa; k_w = weighted kappa; NR = not reported. [1] Raimen & Manske (2011); [2] Crossley et al. (2011); [3] Davis et al. (2011); [4] Teyhen et al. (2011); [5] Nuzo et al. (2011); [6] Askling et al. (2010); [7] Poulsen & James (2011); [8] Evans et al. (2012); [9] McClure et al. (2012); [10] Frohm et al. (2011); [11] Goldbeck & Davies (2000); [12] Gorman et al. (2012); [13] Ross et al. (2002); [14] Crill et al. (2004); [15] Engebretsen et al. (2010)

In the context of this dissertation, developing a CPM for UE SRI in college baseball players that incorporates the TEAM-S would be a valuable contribution in establishing the instrument's validity in the area of injury prediction.

The assessment of function limitations at the level of the whole person has gained increased importance in athletic populations (Reiman & Manske, 2011). The screening of dysfunctional movement patterns prior to the onset of pain, functional limitations, or injury is an important consideration (Arnason, Tenga, Engebretsen, & Bahr, 2004). Functional screening tools that are sensitive to functional limitations and asymmetry are needed in clinical practice (Bahr, 2009). The FMS™, Frohm's nine-test screening battery, and TEAM-S are viable functional performance screens for quantifying the characteristics of function, injury assessment, sport performance, and injury prediction in athletic populations. However, determining which combination of functional assessment measures best assesses injury risk requires further investigation (Reiman & Manske, 2011). Specifically, the relationship between functional movement screens and injury should be investigated in combination with self-report measures and risk factors (Reiman & Manske, 2011).

Baseball UE SRI Epidemiology

Differing injury rates and incidences have been reported for youth, high school, collegiate and professional baseball levels (Comstock, Collins, & McIlvain, 2011; Dick et al., 2007; Hootman et al., 2007; Janda, 2003; Kerut et al., 2008; Lyman & Fleisig, 2005; Magra et al., 2007; McFarland & Wasik, 1998; Posner et al., 2011). It has been reported that upwards of 164,800 injuries per year are sustained in little league (Pasternack,

Veenema, & Callahan, 1996) and 46,700 injuries per year in high school (Comstock et al., 2011). About 440 major league baseball players per year are placed on the disabled list. In comparison to other sports, baseball has a relatively low overall injury rate of 0.23 per 1,000 athlete exposures (Hootman et al., 2007). The collegiate and professional preseason injury rates (2.87 and 5.73 per 1,000 exposures) have been reported to be higher than in-season injuries rates (1.58 and 0.54 per 1,000 exposures) (Dick et al., 2007; Posner et al., 2011). Injury rates are about three time higher in games (5.78 per 1,000 exposures) than practices (1.85 per 1,000 exposures) (Dick et al., 2007). Despite the relatively low injury rates, the incidence of UE SRI for baseball players increases with competitive level. Incidence rates have been reported to be 5% in little league and high school (Fleisig et al., 2010), 25% in collegiate (Dick et al., 2007), and 50% in professional (Anz et al., 2010) baseball. The primary injuries of concern (associated with extended time loss) are ulnar collateral ligament (UCL) sprains/tears (Cain, Dugas, Wolf, & Andrews, 2003; Domb et al., 2010; Jazrawi et al., 2006; Wood, Konin, & Nofsinger, 2010), superior labrum tears from anterior to posterior (SLAP lesions) (Burkhart & Morgan, 1998; Burkhart & Morgan, 2001; Burkhart, Morgan, & Kibler, 2003), rotator cuff pathologies (Gerstman, Malanga, & Ferrer, 2009; Jobe & Bradley, 1988; Namdari, Baldwin, Ahn, Huffman, & Sennett, 2011; Yanagisawa, Niitsu, Takahashi, & Itai, 2003), and impingement syndromes (Burkhart, 2006; Kuhn, 2009). It has been reported that the severity of these injuries has led to a four-fold increase in elbow and a six-fold increase in shoulder surgical intervention (Fleisig et al., 2006). The rise in serious UE SRI in

baseball has prompted interest in research focused on identifying risk factors for the purpose of injury prevention strategies.

Conclusion

Recently, there has been an increase in the prevalence of serious UE SRI in all levels of baseball which has sparked increased research interest in identifying injury risk factors. A number of investigations have focused on recognizing potential sport-specific injury risk factors but have not approached the issue from an EBP paradigm. The development of a CPM that includes self-reported outcome measures, sport performance risk factors, and FPMs would be a critical step in advancing the body of knowledge. Furthermore, a CPM based on Bayesian statistics (e.g., Sn, Sp, and LRs) would directly assist clinicians in the screening and evaluation of baseball players at risk for UE SRI.

CHAPTER III

METHODOLOGY

The purpose of this research was to develop and assess a preliminary clinical prediction model (CPM) for upper-extremity (UE) sports related injury (SRI) in a retrospective cohort of collegiate baseball players. The research design was a single-center retrospective cohort study.

Participants

In the fall of 2011, 156 Division I athletes from the sports of baseball (n = 37), men's basketball (n = 10), women's basketball (n = 15), cheerleading (n = 18), men's cross-country (n = 13), women's cross-country (n = 10), men's track and field (n = 5), women's track and field (n = 7), women's lacrosse (n = 28), and volleyball (n = 13) participated in High Point University's (HPU) annual pre-participation examination (PPE). An individual from the research team other than this dissertation author provided participants with a verbal and written explanation of the research project. Written informed consent was obtained as approved by the HPU Institutional Review Board. The researchers were unaware of who consented until after completion of screening. Data belonging to subjects who did not consent to voluntary participation were excluded

The HPU PPE consisted of the following: (a) HPU Athletic PPE Form New/Transfer Athlete Medical History Form, (b) HPU Waiver for Athletics, (c) *National*. *Collegiate Athletic Association (*NCAA) HIPAA Form, (d) HPU HIPAA Form, (e) HPU

Athletic Insurance Policy, (f) HPU Medical Insurance Form, (g) NCAA ADHD/ADD Notification Document, and (h) NCAA Sickle Cell Screening Notification Document. Following medical clearance by team physicians, athletes completed the Targeted Enhanced Athletic Movement Screen (TEAM-S) and sport specific pre-season conditioning tests. In addition, UE athletes (volleyball and baseball) completed the Kerlan-Jobe Orthopaedic Clinic overhead athlete shoulder and elbow score (KJOC-SES) in conjunction with the TEAM-S. All testing procedures were standard policy and procedure of the HPU intercollegiate athletic department, athletic training department, and strength and conditioning program.

From the 156 tested athletes, thirty-seven Division I baseball players were selected (age [yrs] 19.53 ± 0.9; height [cm] 183.3 ± 7.1; weight [kg] 85.6 ± 10.5). The baseball players' data from the TEAM-S and KJOC-SES were utilized to develop a CPM for UE SRI in collegiate baseball players. One baseball athlete completed the PPE process and TEAM-S but did not complete the KJOC-SES. This subject's data was excluded from data analysis resulting in a final n = 36.

Instrumentation

The CPM predictive factors were derived from three domains: (a) self-reported outcome measures, (b) sport performance risk factors, and (c) functional performance measures (FPMs). The self-reported outcome measure included the KJOC-SES functional assessment tool as described by Albert et al. (2010) (Appendix A). Sport performance risk factors were a range of variables derived from game-play statistics.

FPMs were derived from the TEAM-S instrument as presented by Hegedus (2011) (see Appendix B). A more in-depth description of each of these three domain areas follows.

Self-Reported Outcome Measures

All participants completed the KJOC-SES (Alberta et al., 2010) (Appendix A). The KJOC-SES is a patient-centered, self-report outcome measure specific to overhead athletes. The instrument requests information about UE SRI history, level of competition, and contains a 10-item physical functional inventory. The KJOC-SES UE SRI history information for each participant was reviewed and coded by the principal investigator as "1" for positive history or "0" for a negative history. Dichotomizing UE SRI history allowed the establishment of a criterion reference for establishing two groups: injured and non-injured. A self-reported UE SRI was operationally defined by one or more of the following conditions: ulnar collateral ligament (UCL) sprains/tears (Cain et al., 2003; Domb et al., 2010; Jazrawi et al., 2006; Wood et al., 2010), superior labrum tears from anterior to posterior (SLAP lesions) (Burkhart & Morgan, 1998; Burkhart & Morgan, 2001; Burkhart, Morgan, et al., 2003), rotator cuff pathologies (Gerstman et al., 2009; Jobe & Bradley, 1988; Namdari et al., 2011; Yanagisawa et al., 2003), and impingement syndromes (Burkhart, 2006; Kuhn, 2009).

Each KJOC-SES physical functional inventory item (e.g., Item 1: "How difficult is it for you to get loose or warm prior to competition or practice?"; Item 4: "How unstable does your shoulder or elbow feel during competition?"; Item 9: "How much has your control (of pitches, serves, strokes, etc.) suffered due to your arm?" was scored on a 10-cm visual analog scale. The 10 physical functional inventory items yielded a total

score (100 maximum points) as previously described by Alberta et al. (2010). A Lower score represents lesser perceived function.

Sport Performance Risk Factors

Individual game-by-game statistics for the 2009, 2010, and 2011 baseball seasons were publicly available from the HPU sports information department web site. The sport performance risk factors derived from game statistics encompassed the following variables: playing position, average game appearances per season (GA) by playing position, average innings pitched per season per season (IP), average number of pitches per season (NP), average number of pitches per game appearances per season (NP/GA), average number of pitches per innings pitched per season (NP /IP), and average at-bats per season (AB). Subjects were dichotomously labeled "pitcher" or "fielder" based on an athlete's primary playing position. Direct game play exposure was determined from GA, IP, NP, NP/ GA, NP/IP, and AB. Sport Performance variables are listed in Table 9.

Table 9. Independent Variables for CPM Development: Self-Report Measures and Sport Performance Risk Factors

Domain	Predictor Variable(s)	Variable Type
Self-Report Measures		
	KJOC-SES Score	Continuous
Sport Performance Risk Factors		
	playing position	Nominal
	game appearances- pitcher[a]	Continuous
	game appearances- fielder[a]	Continuous
	innings pitched[a]	Continuous
	number of pitches[a]	Continuous
	number of pitches per game appearance[a]	Continuous
	number of pitches per inning[a]	Continuous
	at-bats[a]	Continuous

Note. [a]average per season.

Functional Performance Measures

FPMs were derived from the TEAM-S (Hegedus, 2011) (Appendix B). The TEAM-S is a 15-item screening battery that also includes a qualitative dyskinesis screening test as a separate item for UE dominant athletes (baseball and volleyball). The TEAM-S was scored as described by Hegedus (2011) with individual items being scored on 6-point rating (0, 1, 2, 3, 4, 5) based on specific scoring criteria. For items that had recorded left and right measures, the lower score was utilized in determining the item's rating scale score. A brief summary of individual TEAM-S item scoring criteria is provided in Table 10 and described in the TEAM-S scoring sheet (see Appendix B). A TEAM-S composite score was derived by summing the 15 items and the qualitative dyskinesis screening test for a maximum score of 80 points. Table 10 provides a list of the individual TEAM-S items and their respective scoring metrics.

The TEAM-S was administered by a group of clinicians consisting of two physical therapists, three athletic trainers, two certified strength and condition coaches, and three undergraduate exercise science students. Experienced raters reviewed the TEAM-S scoring sheet and received verbal instructions on the procedure for administering the TEAM-S battery of FPMs from the research team's principal investigator (E. J. Hegedus) prior to data collection. Student raters underwent a similar orientation, but also were required to observe a group testing session prior to data collection. Student raters were intentionally assigned TEAM-S items that required timekeeping and repetitive counting skills. The intra- and inter-rater reliability for experienced and student raters was not determined.

Table 10. Functional Performance Measures: TEAM-S Item Scoring Criteria

TEAM-S Item		Predictor Variable(s)	Rating Scale	Scoring Criteria
1	Beighton Hypermobility	Brighton Score	0 to 5	Beighton index
2	Full Squat	Full Squat Score	0 to 5	Qualitative assessment
3	Single Leg Squat[a]	Single Leg Squat Score	0 to 5	Qualitative assessment
4	Downward Dog	Downward Dog Score	0 to 5	Qualitative assessment
5	Active Straight Leg Raise	Active Straight Leg Raise Score	0 to 5	Qualitative assessment
6	Shoulder Mobility Test[a]	Shoulder Mobility Test Score	0 to 5	Qualitative assessment
7	Y-Balance for Upper-extremity[a]	Y-Balance Score	0 to 5	Sum of greatest 3 reaches (cm) divided by 3 x 100; percentage of right versus left.
8	CKCuest	CKCuest Score	0 to 5	Number of repetitions in 15 seconds
9	Side Plank Hip Abduction[a]	Side Plank Hip Abduction Score	0 to 5	Number of repetitions in 30 seconds
10	Side Plank Hip Adduction [a]	Side Plank Hip Adduction Score	0 to 5	Number of repetitions in 30 seconds
11	Nordic Hamstring Test	Nordic Score	0 to 5	Knee flexion angle (degrees)
12	Triple Hop for Distance[a]	Triple Hop Score	0 to 5	Total distance (in) jumped on each leg; least distance /greatest distance x 100
13	Vertical Leap	Vertical Leap Score	0 to 5	Vertical jump height (in)
14	In-line lunge for Distance [a]	In-line Lunge Score	0 to 5	Total lunge distance (in) each leg; least distance /greatest distance x 100
15	Lateral Lunge for Distance[a]	Lateral Lung Score	0 to 5	Total lunge distance (in) each leg; least distance /greatest distance x 100
16	Qualitative Dyskinesis Screening Test[a]	Scapula Dyskinesis Score	0 to 5	Qualitative assessment
Total		TEAM-S Total Score[b]	0-80	

Note. Each TEAM-S item is scored on a 6-point rating scale (0-1-2-3-4-5). The criteria for the rating scale are unique to each item and are specified in the TEAM-S scoring sheet, refer to Appendix B; [a]Item measured bilaterally; [b]Team-S Total Score is based on the sum of 16 items; in = inches; cm = centimeters.

TEAM-S items based on left and right side measures were coded based on dominant throwing arm. For right handed dominant throwers, right side UE variables were coded as "throwing arm" and left side UE variables were coded as "non-throwing arm." Lower-extremity (LE) variables were coded as follows: for right handed dominant throwers, right side LE variables were coded as "balance foot" and left side LE variables were coded as "stride foot". TEAM-S variables for left handed dominant throwers were coded similarly, with opposing designations. Coding based on arm dominance allowed for comparisons of throwing arm, non-throwing arm, stride foot, and balance foot in addition to a right versus left comparison. The calculation of UE ratios were derived from the percentage of the throwing arm versus the non-throwing arm. LE ratios were derived from the percentage of the stride foot versus the balance foot. See Table 11 for a listing of UE and LE ratio variables.

Table 11. Independent Variables for CPM Development: Functional Performance Measure Risk Factors

Domain	Predictor Variable(s)	Variable Type
Functional Performance Measures		
	TEAM-S Total Score	Continuous
	Brighton Score	Ordinal
	Full Squat Score	Ordinal
	Single Leg Squat Score	Ordinal
	Single Leg Squat Stride Foot	Ordinal
	Single Leg Squat Balance Foot	Ordinal
	Downward Dog Score	Ordinal
	Active Straight Leg Raise Score	Ordinal
	Active Straight Leg Raise Stride Foot	Ordinal
	Active Straight Leg Raise Balance Foot	Ordinal
	Shoulder Mobility Test Score	Ordinal
	Shoulder Mobility Test Non-Throwing Arm	Ordinal
	Shoulder Mobility Test Throwing Arm	Ordinal
	Y-Balance Score	Ordinal
	Y-Balance Non-throwing Arm (cm)	Continuous
	Y-Balance Throwing Arm (cm)	Continuous
	Y-Balance Ratio [b]	Continuous
	CKCuest Score	Ordinal
	CKCuest Absolute[a]	Continuous
	Side Plank Hip Abduction Score	Ordinal
	Side Plank Hip Abduction Stride Foot Absolute [a]	Continuous
	Side Plank Hip Abduction Balance Foot Absolute [a]	Continuous
	Side Plank Hip Abduction Ratio [c]	Continuous
	Side Plank Hip Adduction Score	Ordinal
	Side Plank Hip Adduction Stride Foot Absolute [a]	Continuous
	Side Plank Hip Adduction Balance Foot Absolute [a]	Continuous
	Side Plank Hip Adduction Ratio [c]	Continuous
	Nordic Score	Ordinal
	Triple Hop Score	Ordinal
	Tripe Hop Stride Foot (in)	Continuous
	Triple Hop Balance Foot (in)	Continuous
	Triple Hop Ratio [c]	Continuous
	Vertical Leap Score	Ordinal
	Vertical Leap Absolute (in)	Continuous
	In-line Lunge Score	Ordinal

Table 11 (continued)

Domain	Predictor Variable(s)	Variable Type
Functional Performance Measures		
	In-line Lunge Stride Foot (in)	Continuous
	In-line Lunge Balance Foot (in)	Continuous
	In-line Lunge Ratio [c]	Continuous
	Lateral Lunge Score	Ordinal
	Lateral Lunge Stride Foot (in)	Continuous
	Lateral Lunge Balance Foot (in)	Continuous
	Lateral Lunge Ratio [c]	Continuous
	Scapula Dyskinesis Score	Ordinal

Note. [a] Number of repetitions; [b] Upper extremity ratio is the percentage of throwing arm versus non-throwing arm; [c] Lower extremity ratio is the percentage of stride foot versus balance foot); in = inches; cm = centimeters.

Approach for Specific Aim One

Specific Aim One was to identify individual factors specific to self-reported outcome measures (as measured by KJOC score), sport performance risk factors (as measured by game statistics and coaching measures), and FPMs (as measured by scores from TEAM-S items) that differed between previously injured and uninjured cohorts. Factors that statistically differed by injury status were retained for additional analysis (Specific Aim Two) to develop a multifactorial CPM. Through the construction of 2x2 contingency tables we determined the diagnostic utility of individual factors (see Tables 9 – 11) that significantly differed between injured and non-injured cohorts. Individual factors were binary coded as positive (1) or negative (0) for injury status and wereexpressed through Bayesian statistics (Sn, Sp, LR+, LR-, and DOR).

Approach for Specific Aim Two

Specific Aim Two was to determine whether the individual factors identified in Specific Aim One collectively would retrospectively predict injury status. Individual factors were analyzed through forward stepwise logistic regression to determine the best combination of factors for predicting injury status. The diagnostic utility of the multifactorial CPM was expressed through Bayesian statistics (Sn, Sp, LR+, LR-, and DOR).

Variables

Independent variables for this study included predictors from the self-reported outcome measures, sport performance risk factors, and FPMs. Tables 10 and 11 provide a detailed list of the independent variables extracted from the self-report outcome measures, sport performance risk factors, and FPMs as previously described. The dependent variable for this study was self-reported history of UE SRI and was categorized as non-injured (0) or injured (1).

Statistical Analyses

After subjects were dichotomously categorized based on UE SRI history to create two outcome groups (non-injured and injured), we determined which factors would be included in the CPM by group (non-injured or injured) comparison of each independent variable using univariate analysis (Specific Aim One). Continuous independent variables were tested using an independent sample *t* test. Nominal categorical independent variables were tested using the *Chi-square* test. Ordinal scale independent variables were tested using the Mann-Whitney U test. This approach for univariate analysis has been

outlined by Bruce & Wilkerson (2010) and was representative of reported statistical approaches for CPM development (Hicks et al., 2005; Raney et al., 2009; Teyhen, Flynn, Childs, & Abraham, 2007). Independent variables with a *p*-value of ≤ 0.1 were retained as potential predictor variables for the CPM (Bruce & Wilkerson, 2010a; Hicks et al., 2005; Raney et al., 2009; Teyhen et al., 2007; Wilkerson et al., 2012). A liberal significance level was utilized for univariate analysis to ensure appropriate identification of potential predictor variables for the subsequent multivariate analysis. The purpose of screening independent variables with a liberal significance level in the derivation phase of developing a CPM was to identify and retain potential predictive values that may individually have a weak relationship to the outcome variable but when combined with other predictive values in a multifactorial model may demonstrate a stronger statistical relationship to the outcome variable (Bruce & Wilkerson, 2010a).

Secondarily for Specific Aim One, statistically significant continuous variables were further analyzed by constructing receiver operator characteristic (ROC) curves. ROC curves were used to establish a cutoff score with the greatest diagnostic utility and to define a positive risk factor. Once a cutoff score was established for each predictor variable, each case was coded as positive (1) or negative (0) with respect to the cutoff score. Contingency tables (2x2) were used to calculate Sn, Sp, LR+, LR-, and DOR with corresponding 95% confidence intervals (CI) based on the cutoff scores. The cutoff scores for significant ordinal variables were based on the whole number score of the injured group. Once a cutoff score was established for each predictor variable, each case was then coded as positive (1) or negative (0) with respect to the cutoff score.

Contingency tables (2x2) were used to calculate Sn, Sp, LR+, LR-, and DOR with corresponding 95% confidence intervals (CI) based on the cutoff scores. Significant nominal variables were coded as positive (1) or negative (0) for each case. 2x2 contingency tables were used to calculate Sn, Sp, LR+, LR-, and DOR with corresponding 95% CI for each respective variable. The purpose of binary coding of statistically significant predictor variables as positive (1) and negative (0) was to establish the diagnostic utility of a given factor in relationship to the outcome variable (non-injured or injured). This allowed for the calculation of the number of true positive, true negative, false positive, and false negative cases in a 2x2 contingency table and the subsequent calculation of Sn, Sp, LR+, LR-, and DOR for each predictor variable.

After completing univariate analysis to determine which predictor variables significantly differed by injury status, a correlational matrix was used to determine whether similar predictor variables were highly correlated. To minimize multicollinearity in logistic regression analysis, redundant correlated variables were eliminated based on the correlational matrix and DOR values prior to generating a final set of variables for multivariate analysis (Pallant, 2010). Forward step-wise logistic regression analysis was used to determine which combination of these predictor variables provided the strongest predictive value of UE SRI history (Specific Aim Two). *A priori* significance was set at $p \leq 0.05$. The multifactorial CPM of injury status was then analyzed per case and input into a 2x2 contingency table for the calculation of Sn, Sp, LR+, LR-, and DOR. Data analysis was performed using IBM® SPSS® V20.0 (SPSS, Inc., Chicago, IL).

CHAPTER IV

RESULTS

The study developed and assessed a preliminary clinical prediction model (CPM) for upper-extremity (UE) sports related injury (SRI) in a retrospective cohort of collegiate baseball players. The research design was a single-center retrospective cohort study. This chapter provides the descriptive data and statistical analyses for each hypothesis.

Participants

A total of thirty-seven Division I baseball players completed the PPE process, TEAM-S, and KJOC-SES. The baseball players' data from the TEAM-S and KJOC-SES were utilized to develop a CPM for UE SRI in collegiate baseball players. One baseball athlete completed the PPE process and TEAM-S but did not complete the KJOC-SES. This subject's data were excluded from the analysis, resulting in a final cohort of 36 participants; (19.5 ±1.0 yrs, 183.3 ± 7.1 cm, 85.6 ± 10.6 kg) with 13.9 ± 3.1 years of playing experience.

The cohort was comprised of 19 (53%) pitchers and 17 (47%) field position players. The prevalence of dominant throwing arm SRI in this cohort (33%) was based on twelve self-reported injuries: five ulnar collateral ligament sprains, three shoulder impingements, two labium pathologies, and two rotator cuff tendinopathies (see Table 12). Based on this self-reported UE SRI history the cohort was divided dichotomously into non-injured (n = 24) and injured (n = 12) groups for univariate analyses.

Table 12. Self-Reported UE SRI

Pathology	Cases (n = 12)
Ulnar Collateral Ligament	5
Shoulder Impingement	3
Labrum	2
Rotator Cuff Tendinopathy	2

Note. UE SRI were for dominant throwing arm.

Self-Reported Outcome Measures

KJOC-SES scores differed significantly (p = .001) between non-injured and injured players (see Table 13).

Sport Performance Risk Factors

The non-injured group was comprised of eight (22%) pitchers and 16 (44%) field position players. The injured group was comprised eleven (31%) pitchers and one (3%) field position player. *Chi square* analysis of injury status by playing position revealed a significantly higher (10.92, df = 1, p = 0.001) injury rate for pitchers than expected.

Sport performance risk factors for average game appearances per season (GA) for pitchers and fielders, average innings pitched per season (IP), average number of pitches per season (NP), average number of pitches per game appearances per season (NP/GA), average number of pitches per innings pitched per season (NP /IP), and average at-bats per season (AB) were not significantly different between the non-injured and injured groups. Summary data for these variables can be found in Table 13.

Table 13. Descriptive Data for Self-Reported Measures and Sport Performance Risk Factors

Domain	Predictor Variable	Non-Injured (n = 24)	Injured (n = 12)	*p*-value
Self-Report Measures				
	KJOC-SES	89.6 ± 9.9	78.1 ± 7.6	.001
Sport Performance Risk factors				
	Playing Position			.001†
	Pitcher	8	11	
	Fielder	16	1	
	GA - Pitcher	6 ± 5.1 (n = 3)	13.3 ± 7.5 (n = 8)	.18
	GA - Fielders	39.7 ± 11.3 (n = 7)	6 (n = 1)	na
	IP	11.4 ± 10.5 (n = 3)	24.7 ± 18.8 (n = 8)	.287
	NP	203.6 ± 213.3 (n = 3)	445.9 ± 372.7 (n = 8)	.325
	NP/GA	27.7 ± 8.1 (n = 3)	35.4 ± 22.9 (n = 8)	.597
	NP/IP	17.4 ± 3.8 (n = 3)	18.2 ± 2.5 (n = 8)	.693
	AB	117.8 ± 73.2 (n = 7)	5.5 (n = 1)	na

Note. mean ± standard deviation; GA = average game appearances per season; IP = average innings pitched per season; NP = average number of pitches per season; NP/GA = average number of pitches per game appearances per season; NP /IP = average number of pitches per innings pitched per season; AB = average at-bats per season.
† Injury Status *Playing Position, *Chi-square* 10.92, df = 1, $p = 0.001$

Functional Performance Measures

Of the sixteen individual TEAM-S scored items, only single leg squat and the CKCUEST differed significantly between injured and non-injured groups. Additional group comparison of predictor variables based on absolute scores—throwing arm dominance (throwing arm, non-throwing arm, stride foot, and balance foot), upper-extremity ratios, and lower-extremity ratios were significantly different between injured

and non-injured for the following variables: single leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder mobility test non-throwing arm, and CKCUEST (absolute score). The TEAM-S total score was not different between the injured and non-injured groups. Table 14 provides a data summary of all TEAM-S predictor variables and total scores.

Collectively, univariate analyses identified nine significant ($p \leq 0.10$) predictor variables: KJOC-SES, playing position (pitcher), single leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder mobility test non-throwing arm, CKCUEST (TEAM-S score), and CKCUEST (absolute score).

To determine a discriminatory cutoff score for injured vs. non-injured, receiver operator characteristic (ROC) curves were constructed for continuous predictor variables. ROC analysis for KJOC-SES yielded a cutoff score of ≤ 86 and an area under the curve of 0.854. ROC analysis for CKCUEST (absolute score) yielded a cutoff score of 24 and an area under the curve of 0.698 (see Appendix E for ROC curves). Cutoff scores were then used to construct two-by-two (2x2) contingency tables and the subsequent calculation of diagnostic utility measures of sensitivity (Sn), specificity (Sp), positive likelihood ratio (LR+), negative likelihood ratios (LR-), and diagnostic odds ratio (DOR). Tables 15 and 16 provide the 2x2 contingency tables for these predictor variables.

Playing position was a significant predictor variable for injury status. Because playing position was dichotomously coded into two categories, pitcher or fielder, a 2x2 contingency table was constructed without the necessity of determining a discriminatory cutoff score. Table 17 provides the 2x2 contingency table for playing position.

Table 14. Descriptive Data for TEAM-S Individual Items and Total Score

Domain	Predictor Variable	Non-Injured (n = 24)	Injured (n = 12)	*p*-value
Functional Performance Measures				
1	Beighton Hypermobility	4.7 ± 0.5 (24)	4.5 ± 0.6 (12)	.266
2	Full Squat	4.4 ± 0.9 (24)	4.3 ± 0.9 (12)	1.00
3a	Single Leg Squat	4.2 ± 0.6 (24)	4.9 ± 0.2 (12)	.005
3b	Single Leg Squat Stride Foot	4.5 ± 0.6 (24)	4.9 ± 0.2 (12)	.041
3c	Single Leg Squat Balance Foot	4.4 ± 0.6 (23)	4.9 ± 0.2 (12)	.015
4	Downward Dog	2.9 ± 1.2 (24)	3.0 ± 1.3 (12)	.498
5a	Active Straight Leg Raise	3.5 ± 0.7 (24)	3.5 ± 0.5 (12)	.955
5b	Active Straight Leg Raise Stride Foot	3.6 ± 0.7 (24)	3.75 ± 0.5 (12)	.683
5c	Active Straight Leg Raise Balance Foot	3.5 ± 0.7 (24)	3.5 ± 0.5 (12)	.955
6a	Shoulder Mobility Test	2.3 ± 0.4 (24)	2.7 ± 0.7 (12)	.136
6b	Shoulder Mobility Test Non-Throwing Arm	2.83 ± 0.5 (24)	3.25 ± 0.4 (12)	.035
6c	Shoulder Mobility Test Throwing Arm	2.3 ± 0.4 (24)	2.8 ± 0.8 (12)	.099
7a	Y-Balance for Upper-Extremity	4.8±0.3 (22)	4.7±0.6 (11)	.668
7b	Y-Balance Non-throwing Arm (cm)	279.9 ± 20.1 (22)	289.9 ± 21.3 (12)	.185
7c	Y-Balance Throwing Arm (cm)	282.3 ± 20.3 (24)	288.6 ± 21.7 (11)	.413
7d	Y-Balance Ratio[b]	1.0 ± 0.0 (22)	1.0 ± 0.1 (11)	.949
8a	CKCUEST	3.9 ± 0.8 (23)	3.3 ± 0.5 (11)	.046

Table 14 (continued)

8b	CKCUEST Absolute[a]	26.0 ± 3.8 (23)	23.8 ± 2.4 (11)	.08
9a	Side Plank Hip Abduction	5.0 ± 0.0 (24)	5.0 ± 0.0 (12)	1.00
9b	Side Plank Hip Abduction Stride Foot Absolute[a]	54.9 ± 11.6 (24)	54.1 ± 8.8 (12)	.837
9c	Side Plank Hip Abduction Balance Foot Absolute[a]	60.6 ± 11.1 (24)	55.75 ± 9.8 (12)	.203
9d	Side Plank Hip Abduction Ratio†	0.91 ± 0.1 (24)	0.98 ± 0.1 (12)	.187
10a	Side Plank Hip Adduction	5.0 ± 0.0 (24)	4.9 ± 0.2 (12)	.157
10b	Side Plank Hip Adduction Stride Foot Absolute[a]	53.3 ± 8.7 (24)	48.9 ± 10.2 (12)	.184
10c	Side Plank Hip Adduction Balance Foot Absolute[a]	54.5 ± 8.8 (24)	52.1 ± 8.8 (12)	.460
10d	Side Plank Hip Adduction Ratio[c]	0.99 ± 0.1 (24)	0.94 ± 0.1 (12)	.463
11	Nordic Hamstring Test	2.5 ± 0.9 (24)	2.5 ± 0.9 (12)	.888
12a	Triple Hop for Distance	4.5 ± 0.5 (24)	4.7 ± 0.4 (11)	.420
12b	Tripe Hop Stride Foot (in)	230.2 ± 21.4 (24)	240.5 ± 30.6 (12)	.260
12c	Triple Hop Balance Foot (in)	228.0 ± 19.3 (24)	240.4 ± 31.1 (12)	.152
12d	Triple Hop Ratio[c]	1.01 ± 0.6 (24)	0.99 ± 0.5 (12)	.434
13a	Vertical Leap	3.8 ± 0.9 (24)	3.4 ± 1.0 (12)	.283
13b	Vertical Leap Absolute (in)	27.0 ± 3.8 (24)	25.4 ± 3.9 (12)	.268
14a	In-line lunge for Distance	4.5 ± 0.8 (24)	4.6 ± 0.6 (12)	.591
14b	In-line Lunge Stride Foot (in)	51.4 ± 5.3 (24)	50.4 ± 4.2 (12)	.559
14c	In-line Lunge Balance Foot (in)	52.2 ± 5.0 (24)	50.8 ± 4.9 (12)	.416

Table 14 (continued)

14d	In-line Lunge Ratio[c]	0.98 ± 0.7 (24)	0.99 ± 0.0 (12)	.711
15a	Lateral Lung for Distance	4.7 ± 0.4 (24)	4.5 ± 0.5 (12)	.460
15b	Lateral Lunge Stride Foot (in)	56.3 ± 4.5 (24)	55.2 ± 4.1 (12)	.492
15c	Lateral Lunge Balance Foot (in)	56.6 ± 5.0 (24)	54.4 ± 5.4 (12)	.243
15d	Lateral Lunge Ratio†	.99 ± 0.4 (24)	1.01 ± 0.1 (12)	.175
16a	Qualitative Dyskinesis	1.1 ± 0.3 (24)	1.1 ± 0.3 (12)	.737
16b	Scapula Dyskinesis Non-Throwing Arm	2.3 ±0.7 (24)	2.5 ±0.6 (12)	.798
16c	Scapula Dyskinesis Throwing Arm	2.2 ±0.8 (24)	2.2 ±0.9 (12)	.552
	Total Score	61.9 ± 3.7 (24)	61.5 ± 4.0 (12)	.951

Note. mean ± standard deviation ;Each TEAM-S item is scored on a 6-point rating scale (0-1-2-3-4-5). The criteria for the rating scale are unique to each item and are specifically outlined in the TEAM-S scoring sheet; refer to Appendix B. [a] Number of repetitions; [b] Upper extremity ratio is the percentage of throwing arm versus non-throwing arm; [c] Lower extremity ratio is the percentage of stride foot versus balance foot); in = inches; cm = centimeters.

Table 15. 2x2 Contingency Table for KJOC-SES Score

		UE SRI		
		Positive	Negative	Total
KJOC-SES ≤ 86	Positive ≤ 86	11 (True positive)	4 (False positive)	15
	Negative > 86	1 (False negative)	20 (True negative)	21
	Total	12	24	36

Table 16. 2x2 Contingency Table for CKCUEST Absolute Score

		UE SRI		
		Positive	Negative	Total
CKCUEST Absolute Score ≤24	Positive ≤ 24	8 (True positive)	7 (False positive)	15
	Negative > 24	3 (False negative)	16 (True negative)	19
	Total	11	23	34

Table 17. 2x2 Contingency Table for Playing Position

		UE SRI		
		Positive	Negative	Total
Playing Position	Pitcher	11 (True positive)	8 (False positive)	19
	Fielder	1 (False negative)	16 (True negative)	17
	Total	12	24	36

The cutoff scores for significant ordinal predictor variables (single leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder mobility test non-throwing arm, and CKCUEST [TEAM-S score]) were based on the whole number score of the injured group. Once a cutoff score was established for each predictor variable, each case was coded as positive (1) or negative (0) and 2x2 contingency tables were used to calculate Sn, Sp, LR+, LR-, and DOR.

Tables 18, 19, 20, 21, 22, and 23 provide the 2x2 contingency tables for Single Leg Squat, single leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder mobility test non-throwing arm, and CKCUEST (TEAM-S score) respectively. Table 24 provides a summary of diagnostic utility measures for all significant predictor variables.

Table 18. 2x2 Contingency Table Single Leg Squat - TEAM-S Score

		UE SRI		
		Positive	Negative	Total
Single Leg Squat TEAM-S Score	Yes 5	11 (True positive)	10 (False positive)	21
	No ≤ 4	1 (False negative)	14 (True negative)	15
	Total	12	24	36

Table 19. 2x2 Contingency Table for Single Leg Squat Stride Foot

		UE SRI		
		Positive	Negative	Total
Single Leg Squat Stride Foot	Yes 5	11 (True positive)	14 (False positive)	25
	No ≤ 4	1 (False negative)	10 (True negative)	11
	Total	12	24	36

Table 20. 2x2 Contingency Table for Single Leg Squat Balance Foot

		UE SRI		
		Positive	Negative	Total
Single Leg Squat Balance Foot	Yes 5	11 (True positive)	12 (False positive)	23
	No ≤ 4	1 (False negative)	12 (True negative)	13
	Total	12	15	36

Table 21. 2x2 Contingency Table for Shoulder Mobility Test Throwing Arm

		UE SRI		
		Positive	Negative	Total
Shoulder Mobility Test Throwing Arm	Yes ≥ 3	7 (True positive)	9 (False positive)	16
	No < 3	5 (False negative)	15 (True negative)	20
	Total	12	24	36

Table 22. 2x2 Contingency Table for Shoulder Mobility Test Non-Throwing Arm

		UE SRI		
		Positive	Negative	Total
Shoulder Mobility Test Non-Throwing Arm	Yes ≥ 3	12 (True positive)	18 (False positive)	30
	No < 3	(0.5) [a] (False negative)	6 (True negative)	6
	Total	12	24	36

Note. [a] The actual false negative rate for the shoulder mobility test non-throwing arm is zero. The calculation of diagnostic utility measures requires a numerical value for each cell within the contingency table. To resolve this issue, 0.5 is substituted for zero.

Table 23. 2x2 Contingency Table for CKCUEST - TEAM-S Score

		UE SRI		
		Positive	Negative	Total
CKCUEST - TEAM-S Score	Yes ≤ 3	7 (True positive)	7 (False positive)	14
	No ≥ 4	4 (False negative)	16 (True negative)	20
	Total	12	23	34

Table 24. Diagnostic Utility Values of Significant Predictor Variables

Predictor Variable	Sensitivity[a]	Specificity	LR+	LR-	DOR
Continuous					
KJOC-SES ≤ 86	0.91 (0.64-0.98)	0.83 (0.64-0.93)	5.5 (2.2-13.6)	0.10 (0.01-0.65)	55.0 (5.4-554.9)
CKCUEST (absolute) ≤ 24	0.72 (0.43-0.84)	0.69 (.49-.84)	2.3 (1.1-4.8)	0.39 (0.14-1.06)	6.0 (1.2-30.0)
Categorical					
Playing Position (pitcher)	0.91 (0.64-0.98)	0.66 (0.46-0.82)	2.7 (1.5-4.9)	0.12 (0.01-0.83)	22.0 (2.3-201.7)
Ordinal					
Single Leg Squat - TEAM-S Score	0.91 (0.64-.98)	0.58 (0.38-0.75)	2.2 (1.3-3.6)	0.14 (0.02-0.96)	15.4 (1.7-139.2)
Single Leg Squat Stride Foot	0.91 (0.64-0.98)	0.41 (0.24-0.61)	1.5 (1.0-2.2)	0.2 (0.02-1.3	7.85 (0.8-71.0)
Single leg Squat Balance Foot	0.91 (0.64-0.98)	0.5 (0.31-0.68)	1.8 (1.1-2.8)	0.16 (0.02-1.1)	11.0 (1.2-99.0)
Shoulder Mobility Test Throwing Arm	0.58 (0.31-0.80)	0.62 (.42-0.78)	1.5 (0.7-3.1)	0.66 (0.31-1.3)	2.33 (0.5-9.5)
Shoulder Mobility Test Non-Throwing Arm	0.96 (0.70-0.99)	0.25 (0.12-0.44)	1.2 (0.99-1.6)	0.16 (0.01-2.6)	8.0 (0.4-156.8)
CKCUEST-TEAM S	0.63 (0.35-0.84)	0.69 (0.49-0.84)	2.0 (0.9-4.4)	0.52 (0.17-1.14)	4.0 (0.8-18.2)

Note. [a] Value (95% Confidence Interval); LR+ = positive likelihood ratio; LR- = negative likelihood ratio; DOR = diagnostic odds ratio

Clinical Prediction Model

Specific Aim Two of this study was to determine whether the individual factors related to self-reported outcome measures, sport performance risk factors statistics, and FPMs identified in Specific Aim One would retrospectively predict injury status in a Clinical Prediction Model (CPM). Within the set of identified risk factor variables, duplication existed among (a) single leg squat, single leg squat stride foot, and single leg squat balance foot, (b) shoulder mobility test throwing arm and shoulder mobility test non-throwing arm, and (c) CKCUEST (TEAM-S score) and CKCUEST (absolute score). Given the relatively low n of the study and the large number (n = 9) of predictor variables, a correlational analyses was performed to determine collinearity of similarpredictor variables (see Table 25). Single leg squat was correlated with the single leg squat stride foot ($p \leq 0.0001$; $r = 0.846$) and the single leg squat balance foot ($p \leq 0.0001$; $r = 0.904$). Shoulder mobility test throwing arm and shoulder mobility test non-throwing arm also were correlated ($p = 0.009$; $r = 0.943$). CKCUEST (TEAM-S score) and CKCUEST (absolute score) had a significant ($p \leq 0.0001$) and very strong positive correlation ($r = 0.901$). Based on these correlational analyses and DOR values, we elected to only retain the single leg squat, shoulder mobility test throwing arm, and CKCUEST (absolute score) for multivariate analysis. Thus, KJOC-SES, playing position, single leg squat, shoulder mobility test throwing arm, and CKCUEST (absolute score) variables were used in a forward step-wise logistic regression to retrospectively predict injury status in the cohort of 36 collegiate baseball players.

Table 25. Correlational Matrix for Predictor Variables

Variable‡		SLS	SLS SF	SLS BL	SHMT TA	SHMT NTA	CKCUEST TEAM-S	CKCUEST (absolute)
SLS	Pearson r	1						
	Sig. (2-tailed)							
	n	36						
SLS SF	Pearson r	.846**	1					
	Sig. (2-tailed)	.000						
	n	36	36					
SLS BL	Pearson r	.904**	.685**	1				
	Sig. (2-tailed)	.000	.000					
	n	36	36	36				
SHMT TA	Pearson r	.367*	.284	.428**	1			
	Sig. (2-tailed)	.028	.093	.009				
	n	36	36	36	36			
SHMT NTA	Pearson r	.039	-.031	.049	.431**	1		
	Sig. (2-tailed)	.821	.857	.775	.009			
	n	36	36	36	36	36		
CKCUEST TEAM-S	Pearson r	-.202	-.076	-.249	-.172	.103	1	
	Sig. (2-tailed)	.251	.671	.156	.330	.562		
	n	34	34	34	34	34	34	
CKCUEST (absolute)	Pearson r	-.177	-.151	-.187	-.213	.057	.901**	1
	Sig. (2-tailed)	.318	.395	.290	.227	.751	.000	
	n	34	34	34	34	34	34	34

Note. ‡SLS = Single Leg Squat; SLS SF = Single Leg Squat Stride Foot; SLS BF = Single Leg Squat Balance Foot; SHMT TA = Shoulder Mobility Test Throwing Arm; SHMT NTA = Shoulder Mobility Test Non-Throwing Arm; **Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.

The resultant model included two predictor variables; playing position and KJOC-SES. Table 26 provides the logistic regression prediction for UE SRI. A test of the full model against a constant-only model was significant (*Chi square* = 22.4, $p < 0.0001$; df = 2).

Table 26. Logistic Regression Prediction of UE SRI

Variables in the Equation									
		B	S.E.	Wald	df	Sig.	Odds Ratio	95% C.I. for Odds Ratio	
								Lower	Upper
Step 1[a]	Playing Position	3.129	1.143	7.502	1	.006	22.85	2.435	214.555
	Constant	-2.773	1.031	7.235	1	.007	.06		
Step *2*[b]	Playing Position	5.002	2.127	5.532	1	.019	148.63	2.301	9599.488
	KJOC	-.179	.076	5.593	1	.018	.83	.721	.970
	Constant	10.817	5.223	4.289	1	.038	49883.39		

Note. [a]Variable(s) entered on step 1: Playing Position; [b]Variable(s) entered on step 2: KJOC; Final model contained two-factors, Playing Position and KJOC-SES.

The full model explained between 48.1% (Cox and Snell R^2) and 67.2% (Nagelkerke's R^2) of the variance in injury status, and correctly classified 85.3% of the cases (81.8% for injured and 87% for non-injured). The strongest predictor for reported UE SRI was playing position with *pitcher* having an odds ratio of 148. This indicates that pitchers were 148.6 times more likely to report an UE SRI. An odds ratio of 0.84 for KJOC-SES (i.e., <1) indicated that for every point lower scored on the KJOC-SES, baseball players were 0.16 times more likely to report a UE SRI.

A 2x2 contingency table for the two-factor statistical model derived from logistic regression was constructed (see Table 27) with the diagnostic utility measures for the model presented in Table 28. The KJOC-SES based on the cutoff score of 86 and playing position (pitcher) were applied to the original raw data (n = 36). Cases which met both KJOC-SES (≤ 86) and playing position (pitcher) were coded as positive (1) while all other cases were coded as negative (0). A 2x2 contingency table based on the application of these predictive factors was constructed (see Table 29). The corresponding diagnostic utility values for the CPM are presented in Table 28.

Table 27. 2x2 Contingency Table for Two-Factor Statistical Model

		UE SRI		
		Positive	Negative	Total
Two-Factor Statistical Model	Yes	*9* (True positive)	*2* (False positive)	*11*
	No	*3* (False negative)	*20* (True negative)	*23*
	Total	*12*	*22*	*34*

Note. The data reflects a two-factor statistical model derived from forward step-wise logistic regression and was comprised of KJOC-SES and Player Position. For the logistic regression analysis, KJOC-SES data were retained in a continuous variable state, while Player Position was binary coded as pitcher (1) and fielder (0).

Table 28. Diagnostic Utility Values of Two-Factor Models

Model	**Sensitivity**	**Specificity**	**LR+**	**LR-**	**DOR**
Statistical Model	0.75 (0.42.- 0.94)	0.90 (0.70-.98)	8.25 (2.1-32.1)	0.27 (0.1-0.74)	30.0 (4.2-211.8)
CPM	0.83 (0.55 - 0.95)	0.95 (0.79 -0.99)	22.0 (2.88-138.5)	0.17 (0.04-0.61)	115.0 (9.32-1418.8)

Note. Value with 95% Confidence Interval; LR+ = positive likelihood ratio; LR- = negative likelihood ratio; DOR = diagnostic odds ratio

Table 29. 2x2 Contingency Table for Two-Factor CPM

		UE SRI		
		Positive	Negative	Total
Two-Factor CPM	Yes	10 (True positive)	1 (False positive)	11
	No	2 (False negative)	23 (True negative)	25
	Total	12	24	36

Note. The data reflect a two-factor CPM comprised of the predictor variables KJOC-SES (≤ 86) and Playing Position (pitcher).

CHAPTER V

DISCUSSION

Baseball is a popular international sport played on youth, high school, collegiate, and professional levels. Over the past decade there has been a disproportional rise in serious upper-extremity (UE) sports related injury (SRI) necessitating surgery (Petty et al., 2004). This trend has led to a call for further clarification of the relationship between risk factors and injury (McHugh et al., 2012). Understanding the relationship between risk factors and UE SRI is complex because most athletes who sustain injury present with multiple risk factors (Petty et al., 2004). Although a number of baseball-specific risk factors have been independently described (Fleisig et al., 2010; Hootman et al., 2007; Olsen et al., 2006; Wilk et al., 2010), a multifactorial model has not been developed to aid in the clinical diagnosis of UE SRI. The collective inclusion of risk factors based on self-reported outcome measures (Domb et al., 2010; Neuman et al., 2011; Thigpen & Shanley, 2011), sport performance risk factors (Fleisig et al., 2010; Olsen et al., 2006), and functional performance measures (FPM) (G. Cook et al., 2006a, 2006b; G. Cook et al., 2010; Kiesel et al., 2007) may be important in establishing a clinical prediction model (CPM) specific to the baseball population. Furthermore, the recent emphasis on the evidence-based practice paradigm in athletic training (BOC, 2010; NATA, 2010) demands consideration of research models that advance patient-oriented clinical practice (Snyder et al., 2008; Valovich McLeod et al., 2008). A CPM that includes patient-

oriented outcome measures may be advantageous in clarifying the relationship between risk factors and baseball specific UE SRI. Thus the purpose of this study was to develop and assess a preliminary CPM for UE SRI in a retrospective cohort of collegiate baseball players. The CPM was derived from injury risk factors specific to self-reported outcome scores, sport performance, and FPM. The main finding of our study was that a two-factor CPM which included player position and a self-reported outcome measure score retrospectively predicted UE SRI in a cohort of collegiate baseball players.

Specific Aim One

Hypothesis one was accepted as KJOC-SES, playing position, single leg squat (Team-S score), squat leg squat stride foot, single leg squat balance foot, shoulder mobility test throwing arm, shoulder mobility test non-throwing arm, CKCUEST (TEAM-S score), and CKCUEST (absolute score) were each independently significant retrospective predictor variables of UE SRI in a cohort of college baseball players.

Self-Reported Outcome Measures

The KJOC-SES previously has been employed as a population-appropriate self-report outcome measure for baseball players (Alberta et al., 2010; Domb et al., 2010; Neri et al., 2010; Neuman et al., 2011). Our reported KJOC-SES values for injured and non-injured athletes were consistent with previously reported scores. Table 30 provides a details summary of KJOC-SES values for this study and previous investigations.

Table 30. Summary of Reported KJOC-SES Values

Category /Injury Status	KJOC-SES	Cutoff Score	Sn (%)	Sp (%)
Alberta et al (2010)				
Playing without Arm Pain	97.5 (7.8)[a]			
Playing with Pain	64.1 (20.0) [a]			
Not Playing with Pain	44.9 (16.2) [a]			
No Injury	93.3 (11.2) [a]			
Elbow Injury	80.0 (23.3) [a]			
Shoulder Injury	64.7 (24.7) [a]			
Domb et al. (2010)		< 81.3	100 [b]	90 [b]
Control -	95.4 (93.8-97)[c]			
Playing without Arm Pain	90.4 (86.7-94.2)[c]			
Playing with Pain	73.5 (63.6-83.3)[c]			
Not Playing with Pain	47.5 (35.8-59.3)[c]			
Wei et al. (2010)				
Medial elbow pain	60.3[f]			
Neuman et al. (2011)				
All Cases -Type II SLAP	73.6 (39-100)[d]			
Pitcher	73 (39.5-95)[d]			
Position Player	70.5 (39-92.5)[d]			
Neri et al. (2011)				
Control	96.4 (8.3)[a]			
Type II SLAP Lesion	76.9 (63.5-92.5)[e]			
Jones et al (2012)				
Anterior Shoulder Instability	82 (18.2)[a] (range 28-100)			
Krautler et al. (2012)	94.8 (92.9-96.7)[c]			
Current Investigation		≤ 86	91 (65-99)[c]	83 (70-87)[c]
Previously Non-injured	89.6 (9.9)[a]			
Previously Injured	78.1 (7.6)[a]			

Note. Sn = sensitivity; Sp = specificity; [a] mean with standard deviation; [b] 95% confidence intervals not reported; [c] mean with 95% confidence intervals; [d] mean with range; [e] mean with interquartile (25%-75%) range, [f] mean reported only. Alberta et al. (2010), cross validation of KJOC-SES in 282 overhead athletes, 211 of which were baseball players; Domb et al. (2010), 55 professional baseball players who underwent UCL reconstruction; Wei et al. (2010), 9 Little League pitchers with recent history of medial elbow pain; Neuman et al. (2011), retrospective review of 30 arthroscopic repairs of symptomatic type II SLAP lesion; Neri et al. (2011), 23 elite overhead athletes more than 1 year post arthroscopic repair of type II SLAP lesion; Jones et al. (2012), 20 overhead athletes who underwent arthroscopic capsular plication for anterior shoulder instability; Krautler et al. (2012), 44 asymptomatic professional pitchers.

The KJOC-SES values with respect to UE SRI have been validated primarily through retrospective descriptive studies (Alberta et al., 2010; Domb et al., 2010; Hsu et al., 2009; Neri et al., 2010; Neuman et al., 2011). In asymptomatic overhead athletes, KJOS-SES scores were reported to range from 94.4 to 96.4 (Alberta et al., 2010; Domb et al., 2010; Kraeutler et al., 2012; Neri et al., 2010). Albert et al. (2010) reported mean KJOC-SES ranging from 64.7 (elbow) to 80.0 (shoulder) in those with a positive history of injury. In overhand athletes who underwent arthroscopic repair of Type II SLAP lesions, KJOC-SES scores ranged from 76.9 (Neri et al., 2010) to 73.6 (Neuman et al., 2011). In overhand athletes who underwent arthroscopic capsular plication for microtraumatic anterior shoulder instability had average KJOC-SES scores of 82 (Hsu et al., 2009). In professional baseball players who had undergone UCL reconstruction KJOC-SES scores ranged from 47.5 (not playing because of arm pain) to 90.4 (playing without arm pain) with a cutoff score of <81.3 (Domb et al., 2010). In Little League pitchers with medial elbow pain the KJOC-SES score averaged 60.3 (Sweitzer et al., 2012). Our KJOC-SES values were 89.6 (non-injured) and 78.1 (injured) with a discriminatory threshold of <86 identifying athletes with a positive UE SRI history. Thus, the KJOC-SES scores from this study were consistent with previously reported values (Alberta et al., 2010; Domb et al., 2010; Neri et al., 2010).

In the current study, KJOC-SES values had the strongest individual diagnostic utility (see Table 24) of all measures assessed. A KJOC-SES threshold score of ≤ 86 (positive test) yielded high Sn of 91% and Sp of 83%. A Sn of 91% indicates a high probability of a positive test (KJOC-SES ≤ 86) in athletes *with* a history of UE SRI.

Conversely, a KJOC-SES score of >86 (negative test) with a Sn of 88% indicates a high probability of a negative score in athletes *without* a history of UE SRI. Collectively, KJOC-SES, Sn, and Sp demonstrate a very low false negative and slightly higher false positive (see Table 15).

Corresponding KJOC-SES likelihood ratios were LR+ = 5.5; LR- = 0.1. An LR+ >5 is interpreted as a moderate, important shift in pre-test to post-test probability while a LR- ≤0.1 yields a large, conclusive shift (Glynn & Weisbach, 2011; Guyatt et al., 2008). The interpretation of likelihood ratios for the KJOC-SES reiterates that a positive test (KJOC-SES ≤ 86) produced moderate diagnostic utility as an individual predictor of UE SRI. Based on our UE SRI prevalence of 33% (pre-test odds), a positive test (KJOC-SES ≤86) shifts the post-test probability to approximately 75%. A negative test (KJOC-SES>86) shifts the pre-test probability of 33% to a post-test probability of < 3%. These shifts in probability based on a KJOC-SES cutoff score of ≤ 86 indicate that both positive and negative test results provide greater clarity in the diagnostic screening of UE SRI. Figure 4 provides a representation of Fagan's nomogram based on our pretest probability for UE SRI and the associated likelihood ratios for the KJOC-SES.

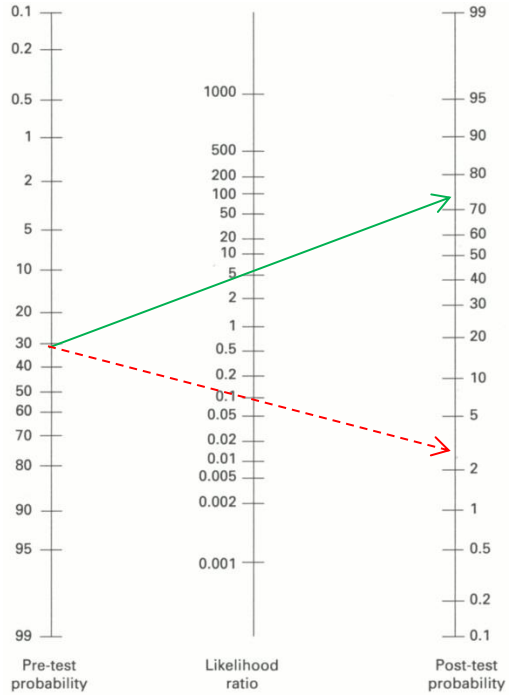

Figure 4. Fagan's Nomogram for KJOC-SES ≤ 86.
Fagan's nomogram taken from Glasziou (2001); For a positive test (KJOC-SES ≤ 86) the solid line represents pre-test probability 33% shifting to a post-test probability of 75% based on a LR+ of 5.5; For a negative test (KJOC-SES > 86, the dashed line represents pre-test probability of UE SRI of 33% shifting to post-test probability of 3% based on a LR- of 0.1.

KJOC-SES, Sn and Sp, have been reported previously as 100% and 90%, respectively with a cutoff score of < 81.3 (Domb et al., 2010). The KJOC-SES diagnostic utility measures reported by Domb et al. (2010) were based on a cohort (n = 55) of professional baseball players who underwent UCL reconstruction surgery. Our subject pool was comprised of college level athletes who self-reported a variety of shoulder and elbow SRI, five of which were UCL. Alberta et al. (2010) reported different KJOC-SES scores among athletes with a history of elbow (80.0 ± 23.3) and shoulder (64.7 ± 24.7) injuries. Because KJOC-SES values may differ based on joint

specificity, it is difficult to provide a direct comparison of our KJOC-SES diagnostic utility values with previously reported values. Indirectly, our data appear consistent with Domb et al. (2010).

Collectively, the diagnostic utility of the KJOC-SES ≤ 86 cutoff was clinically useful in delineating between injured and non-injured athletes based on retrospective analysis of UE SRI. The combination of a very low false negative rate, high Sn, and low LR- suggests that the KJOC-SES, as a stand-alone clinical measurement, may be an excellent diagnostic screening tool in predicting UE SRI.

Sport Performance Risk Factors

Playing position was the only significant sport performance risk factor in distinguishing injured and non-injured groups, as pitchers had higher self-reported UE SRI rates compared to fielders (see Table 13). This finding was consistent with existing evidence that UE SRI rates are higher among pitchers than field position players (Chambless et al., 2000; Fleisig et al., 2010; Kerut et al., 2008; Olsen et al., 2006).

Playing position yielded low to moderate diagnostic utility as an individual predictor variable for UE SRI. Playing position, coded positive test *(*pitcher) and negative test (fielder) had a high Sn of 91% but a moderate Sp of 66%. Furthermore, it is important to recognize that playing position as a diagnostic screening measure was associated with a low false negative rate (2.7%) but a high false positive rate (22.2%). This suggests that a positive result (pitcher) over-identified the presence of UE SRI in non-injured athletes. Subsequently, in the context of a high Sn and moderate Sp, a negative test (fielder) was more valuable at ruling out the probability of an UE SRI.

The likelihood ratios for playing position were LR+ = 2.75; LR- = 0.12. An LR+ between 2 and 5 is interpreted as having a small but sometimes important shift in pre-test to post-test probability while a LR- between 0.1 and 0.2 yields a moderate, important shift (Glynn & Weisbach, 2011; Guyatt et al., 2008). The interpretation of likelihood ratios by playing position demonstrates that a positive test (pitcher) produced low diagnostic utility as an individual predictor variable for UE SRI. Based on our UE SRI prevalence of 33.3% (pre-test odds), a positive test shifts the post-test probability to 47.8%. Conversely, a negative test (fielder) shifted the pre-test probability from 33% to a post-test probability of 3.8%. These shifts in probability based on playing position indicate that a negative test (fielder) provided greater diagnostic clarity versus a positive test (pitcher). Figure 5 provides a representation of Fagan's nomogram based on our pretest probability for UE SRI and the associated likelihood ratios for playing position.

Collectively, pitchers had a higher injury rate than fielders. However, the diagnostic utility of playing position provides low predictive value in relationship to UE SRI history. This conclusion is based on two important factors. First, a high false positive rate overestimates the presence of UE SRI. Second, due to the high Sn and moderate Sp, a negative test (fielder) provides a stronger prediction of *not* having an UE SRI versus having a history of UE SRI. Generally, diagnostic tests with high Sn are useful in identifying people without a target condition because of a very low false negative rate (Jewell, 2011).

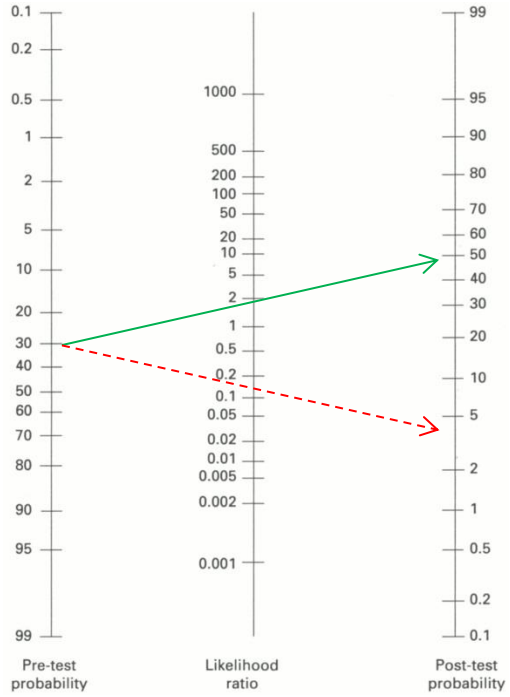

Figure 5. Fagan's Nomogram for Playing Position.
Fagan's Nomogram taken from Glasziou (2001);For a positive test (pitcher), the solid line represents a pre-test probability of 33% shifting to post-test probability of approximately 47.82% based on a LR+ of 2.75; For a negative test (fielder), the dashed line represents a pre-test probability of 33.3% shifting to a post-test probability of 3.8% based on a LR- of 0.12.

The diagnostic utility of playing position is an illustrated case of the mnemonic "**SnNout"**: high **Sen**sitivity, a **N**egative test rules **out** the diagnosis (Portney & Watkins, 2009; Sackett et al., 1997). The interpretation of Sn often seems counterintuitive in clinical practice. Diagnostic measures with high Sn are useful in identifying people without a target condition because of their very low false negative rate. Logically it may be assumed that a positive test result would translate as ruling in the presence of a target condition. However, Sn does not account for false positive results. Sn must be viewed in the context of Sp which does account for false positive test results. Thus, when

adiagnostic test with a high Sn yields a negative test result, there is greater certainty in ruling out the target condition. Despite pitchers having a higher injury rate than fielders, playing position as a diagnostic utility measure provides greater clinical interpretive value when negative (fielder coded as negative).

The remaining sport performance risk factors of average game appearances per season (GA) for pitchers and fielders, average innings pitched per season per season (IP), average number of pitches per season (NP), average number of pitches per game appearances per season (NP/GA), average number of pitches per innings pitched per season (NP/IP), and average at-bats per season (AB) did not differ between the non-injured and injured groups. Theses finding are contrary to the reported link between select sport performance variables and UE SRI. Specifically, throwing volume as measured through IP, NP, GA has been reported as a primary predisposing risk factor for UE SRI (Bradbury & Forman, 2012; Fleisig et al., 2010; Kohlmeyer, 2005; Olsen et al., 2006). Throwing volume is a distinct sport-related extrinsic risk factor that contributes to acute and overuse UE SRI (Fleisig et al., 2010; Lockard, 2006; Olsen et al., 2006). Subsequently, injury prevention strategies universally center on restricting IP, NP, and GA (Andrews & Fleisig, 1998; Fleisig et al., 2010; Fleisig & Andrews, 2012; Fleisig, Weber, Hassell, & Andrews, 2009; Olsen et al., 2006; Sciascia & Kibler, 2006). Thus we included measures of throwing volume as sport performance risk factors to parallel the recent work of Olson et al. (2006) and Fleisig et al. (2010). However, the current investigation did not support the relationship between UE SRI and throwing volume based on the sport performance measures of GA, IP, NP, NP/GA, NP/IP, or AB.

The inability of using sport performance measures of GA, IP, NP, NP/GA, NP/IP, or AB to predict UE SRI in our study may have been due to a number of factors. First, our sample size may have been too small to provide the statistical power necessary to determine whether a difference existed between injured versus non-injured athletes. Second, the retrospective availability of individual game-by-game statistics was not equitable for all subjects across groups. Individual game-by-game statistics were only available for 11 of the 19 (58%) pitchers and eight of 17 (47%) fielders. This was attributed to redshirt or first year players who had not yet participated in games to generate game-by-game statistics. Third, the use of game play statistical data to establish injury risk has only been demonstrated in a retrospective case with a control group design (Olsen et al., 2006) and a 10-year prospective cohort design using adolescent baseball players (Fleisig et al., 2010). Ultimately, the relationship between game play statistics and injury risk remains to be established for collegiate and professional baseball populations.

Functional Performance Measures

FPMs were obtained through the Targeted Enhanced Athletic Movement Screen (TEAM-S) global battery of physical performance measures. The TEAM-S composite score did not differ between injured and non-injured groups. This contradicts findings that an FPM battery (e.g., FMS™) could predict prospectively serious injury in professional football players (Kiesel et al., 2007). However, more recently a growing body of evidence has called into question the validity of FPM batteries to predict injury in active military service members (Teyhen et al., 2012) and collegiate athletes (Winke,

Dalton, Mendell, & Nicchi, 2012). It is believed that individual functional performance test scores derived from an FPM battery may be more predictive of specific injury types than a composite FPM score (Winke et al., 2012). The absence of a significant TEAM-S composite score supports an emerging body of evidence that questions the validity of composite FPM scores in predicting those at risk of injury.

From the individual measures that comprise the TEAM-S battery, a compilation of 45 individual predictor variables (see Table 14), only seven differed significantly between non-injured players and those with UE SRI: (a) single leg squat (TEAM-S), (b) single leg squat stride foot, (c) single leg squat balance foot, (d) shoulder mobility test-throwing arm, (e) shoulder mobility test- non-throwing arm, (f) CKCUEST (TEAM-S), and (g) CKCUEST (absolute score).

Single Leg Squat

The measures of single leg squat (TEAM-S), single leg squat stride foot, and single leg squat balance foot were considered qualitative measures of dynamic lumbopelvic control during a unilateral squat (see Appendix B). The injured group scored higher in all three measures versus the non-injured group. This finding contradicts the common assumption that injured athletes typically present with balance deficits compared to non-injured athletes (Hrysomallis, 2011). Previous investigations have demonstrated a relationship between lower balance scores with respect to pitching performance (Chaudhari, McKenzie, Borchers, & Best, 2011; Hrysomallis, 2011; Marsh, Richard, Williams, & Lynch, 2004). However, a relationship between lower extremity balance and UE injury rates has not been found (Chaudhari et al., 2011; Donatelli et al.,

1999). Because of this evidence, it is unknown why our data demonstrated higher single leg squat scores in the injured group.

Single leg squat (TEAM-S), single leg squat stride foot, and single leg squat balance foot collectively demonstrated poor diagnostic utility (see Table 24). All three measures yielded the same Sn of 91% (95% CI 64 - 98) with Sp values ranging from 41% (95% CI 24 – 61) to 58% (95% CI 38 - 75). Although these Sn and Sp values are representative of established orthopedic special tests (C.E. Cook & Hegedus, 2013), all three measures present with high false positive rates ranging between 27.7 to 36% (see Tables 18, 19, and 20).

The likelihood ratios ranges for the three single leg squat measures are LR+ = 1.5 to 2.2 and LR- = 0.1.4 to 0.2; they provide very small diagnostic utility and are clinically irrelevant. The single leg squat (Team-S) yielded higher quality likelihood ratios compared to single leg squat stride foot and single leg squat balance foot with an LR+ = 2.2 and an LR- = 0.14. Based on our UE SRI prevalence of 33.3% (pre-test odds), a positive test (score of 5) shifts the post-test probability to 42.8%, while a negative test (score $\leq$4) shifts the post-test probability to 4.4%. These shifts in probability are of little help in making clinical decisions about injury status.

Collectively, single leg squat (TEAM-S), single leg squat stride foot, and single leg squat balance foot are confounding positive findings with respect to common clinical thinking. The diagnostic utility of the measures are characterized by high false positive rates, moderate Sp, and low LRs. As stand-alone diagnostic screening measures, single

leg squat measures demonstrate significant values in delineating between injured and non-injured, but in a clinical context do not provide substantial diagnostic utility.

Shoulder Mobility Test

Specific adaptations in passive and active range of motion (ROM) patterns have been reported for overhead throwing athletes. Passive external rotation (ER) and internal rotation (IR) at 90° abduction in the throwing shoulder have been measured between 128 and 142°, and between 55 and 68° respectively, compared to 119 to 135° and 68 to 78° in the non-throwing shoulder (Borsa et al., 2006; Borsa et al., 2005; Crockett et al., 2002; Lintner, Mayol, Uzodinma, Jones, & Labossiere, 2007). This loss of IR has been termed glenohumeral internal rotation deficit (GIRD) and is hypothesized to result in greater forces being absorbed by the shoulder and/or elbow complex. Although GIRD has been identified in those with UE SRI (Bach & Goldberg, 2006; Laudner, Sipes, & Wilson, 2008; Lintner et al., 2007; Tokish, Curtin, Kim, Hawkins, & Torry, 2008), the current study did not include direct glenohumeral joint ROM measures. Instead, the shoulder mobility test provided a dynamic assessment of UE ROM (see Appendix B), which revealed no significant difference in shoulder mobility test scores between the throwing and non-throwing arm. This finding contradicts the reported adaptive ROM patterns specific to throwing athletes that result in ROM asymmetry between dominant and non-dominant throwing arms. Unexpectedly, we found lower shoulder mobility test scores in the throwing arm than in the non-throwing arm irrespective of UE SRI status. Again, this finding contradicts evidence indicating a loss of glenohumeral ROM, particularly GIRD,

is related to an increased risk of UE SRI. Additionally, our finding seems to indicate that the shoulder mobility test may not be a valid ROM measure for baseball players.

Typically the ROM values of the dominant arm are used as a risk factor for UE SRI. However, diagnostic utility measures of the shoulder mobility test scores (≥ 3) were stronger for the non-throwing arm (albeit low quality) than the throwing arm (see Table 24). A positive shoulder mobility test non-throwing arm score (≥ 3) yielded zero false negative test results but a 50% false positive rate (see table 22). The diagnostic utility measures for shoulder mobility test non-throwing arm (≥ 3) yielded a very high Sn (96%), very low Sp (25%) and very small, clinically irrelevant likelihood ratios with overlapping 95% confidence intervals (see Table 24). A high Sn and low Sp may initially appear to be clinically valuable; however, overlapping likelihood ratios render the shoulder mobility test non-throwing arm (≥ 3) clinically useless as an individual screening tool for UE SRI.

Current data collectively indicate that ROM as an injury risk factor in baseball players should not be assessed dynamically as is the shoulder mobility test. Our shoulder mobility test throwing arm and shoulder mobility test non-throwing arm scores resulted in an atypical statistical and clinical relationship between injured and non-injured athletes. The diagnostic utility of both shoulder mobility tests are of poor quality and are difficult to interpret in screening for UE SRI. Although reported to be reliable (Frohm et al., 2011; Teyhen et al., 2012), the measure needs to be validated with respect to traditional shoulder ROM measures in overhead throwing populations to determine its value as a screening measure.

CKCUEST

The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) was developed as a functional UE test to quantify patient progress in rehabilitation settings (Roush, Kitamura, & Waits, 2007). Our reported CKCUEST (absolute score) values ranged from 23.8±2.4 (injured) to 26.0±3.8 (non-injured). The CKCUEST (absolute score) values in the non-injured group were consistent with reference values for the CKCUEST scores ranging from 27.8 ±1.8 in college-aged males (Ellenbecker, Manske, & Davies, 2000) to 30.41±3.4 in healthy, non-injured collegiate baseball players (Roush et al., 2007). Normative values for CKCUEST in injured athletes had not been reported previously. Our ROC analysis for CKCUEST (absolute scores) yielded a cutoff score of ≤ 24 as the discriminatory threshold associated with UE SRI.

The CKCUEST (TEAM-S) and CKCUEST (absolute score) demonstrated similar outcomes with the injured group scoring lower than the non-injured group. Because the scoring metric for CKCUEST (TEAM-S) has a direct relationship with the number of touches in 15 seconds (CKCUEST absolute score) (see Appendix B), similar 2x2 contingency tables (see Tables 16 and 23) and measures of diagnostic utility (see Table 24) were found when comparing the measures. Because the CKCUEST (≤ 24) is a direct reflection of raw data and demonstrated a higher diagnostic odds ratio (DOR) than CKCUEST (TEAM-S), the diagnostic utility of this FPM is best represented by the CKCUEST (≤ 24) data.

A CKCUEST threshold cutoff score of ≤ 24 (positive test) yielded modest Sn of 72% and Sp of 69%. A Sn of 72% indicates a higher probability of a positive test

(CKCUEST ≤ 24) in athletes *with* a history of UE SRI and was subject to an 8.8% false negative rate. Conversely, a CKCUEST score of > 24 (negative test) yielded a Sn of 69%, indicating a higher probability of a negative score in athletes *without* a history of UE SRI, but is limited by high false positive rate (20.5%).

The corresponding CKCUEST(< 24) likelihood ratios of LR+ = 2.3 and LR- = 0.39 indicate that a positive test (score ≤ 24) produced modest diagnostic utility as an individual predictor variable for UE SRI. Based on our UE SRI prevalence of 33% (pre-test odds), a positive test (CKCUEST ≤ 24) shifted the post-test probability to approximately 43.3% while a negative test (CKCUEST > 24) shifted the pre-test probability from 33% to a post-test probability of 11.5%. These shifts in probability based on a CKCUEST cutoff score of ≤ 24 indicate that a positive or negative test result provides little diagnostic clarity in the screening of UE SRI.

Despite significant outcomes, the global diagnostic utility of the CKCUEST ≤ 24 is not clinically useful in delineating between injured and non-injured athletes based on retrospective analysis of UE SRI. The combination of a very high false positive rate, moderate Sn and Sp, and low LRs indicates that the CKCUEST as a stand-alone clinical measurement should not be used as a stand-alone diagnostic screening tool in predicting UE SRI.

Specific Aim Two

Hypothesis two was accepted as a two-factor CPM, comprised of KJOC-SES and playing position, retrospectively predicted UE SRI in a cohort of college baseball players with a greater degree of diagnostic utility than did the individual factors of KJOC-SES,

playing position, single leg (Team-S score), squat leg squat-stride foot, single leg squat-balance foot, shoulder mobility test-throwing arm, shoulder mobility test-non-throwing arm, CKCUEST (TEAM-S Score), and CKCUEST (absolute score).

Clinical Prediction Model

The forward step-wise logistic regression analysis produced a two-factor statistical model comprised of KJOC-SES and playing position. This model was based on n = 34 because CKCUEST data were missing for two subjects. It should be noted that for the logistic regression analysis, continuous predictor variables (KJOC-SES and CKCUEST) were retained in their natural state rather than dichotomized based on receiver operator characteristic (ROC) curve cutoff values to preserve the integrity of the statistical approach. The resultant statistical model yielded a strong set of diagnostic utility measures: Sn of 75% (95% CI: 42 to 94); Sp of 90% (95% CI: 70 to 98); LR+ of 8.25 (95% CI: 2.11 to 32.18); and LR- of 0.28 (95% CI: 0.1 to 0.74).

The two-factor statistical model was applied to the original data set using the ROC curve cutoff value for KJOC-SES and playing position. This provided the opportunity to maximize the number of available subjects and to test the statistical model clinically. Because the KJOC-SES is scored on a continuous scale (0 to 100), it is difficult for a clinician to translate a score into a positive or negative finding without a normative reference score. A KJOC-SES cutoff score ≤ 86 allows a clinician to interpreter the instrument's results as positive or negative for diagnostic purposes. Therefore, applying the two-factor model based on a KJOC-SES ≤ 86 and playing position (pitcher) allowed the logistical regression statistical model to be translated into a

simplified set of clinical diagnostic parameters. In essence this allows a statistical model to become an accessible *clinical* model (CPM) that can be applied directly in a patient context.

The two-factor CPM applied to the original 36 subjects based on KJOC-SES ≤ 86 and playing position (pitcher) yielded diagnostic utility measures as follows: Sn of 83% (95% CI: 0.55 to 95); Sp of 95% (95% CI: 79 to 99); LR+ of 22.0 (95% CI: 2.88 to 138.5); and LR- of 0.17 (95% CI: 0.04 to 0.61). By comparison, the CPM demonstrated improved diagnostic utility for Sn, Sp, LRs, and DOR compared to the primary statistical model (see Table 28). A Sn of 83% is indicative of a high probability of a positive test in athletes with a history of UE SRI, while an Sp of 95% indicates a high probability of a negative score in athletes without a history of UE SRI. Collectively the two-factor CPM demonstrated both low false negative (2.7%) and false positive (5.5%) rates (see Table 28). The CPM's likelihood ratios were 22.0 (LR+) and 0.17 (LR-) and affirm that positive and negative test results are equally important in predicting injury status. Based on our UE SRI prevalence of 33% pre-test odds, a positive test shifts the post-test probability to approximately 88%. A negative test shifts the pre-test probability from 33% to a post-test probability of < 5.3%. These shifts in pre-test to post-test probability are large and conclusive for diagnostic use. Figure 6 provides a representation of Fagan's nomogram based on our pretest probability for UE SRI and the associated likelihood ratios for the two-factor CPM.

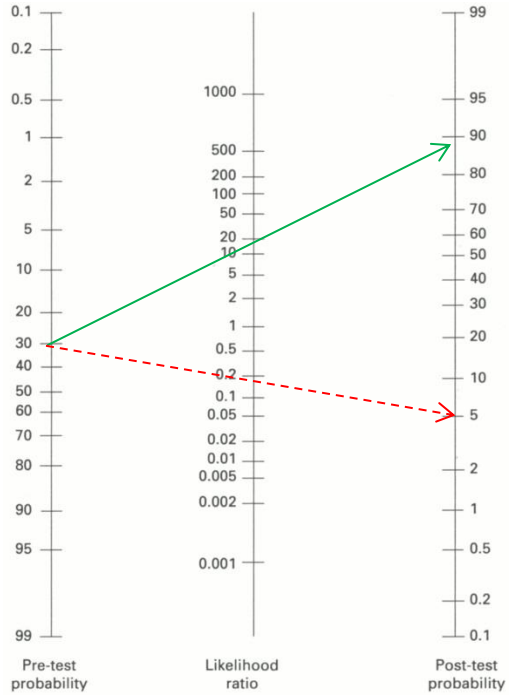

Figure 6. Fagan's Nomogram for Two-Factor CPM.
Fagan's nomogram taken from Glasziou (2001); For a positive screen, solid line represents pre-test probability 33% shifting to post-test probability of 88% based on a LR+ of 22.0; For a negative screen, the dashed line represents pre-test probability of UE SRI of 33% shifting to post-test probability of 5.3% based on a LR- of 0.17.

To the best of our knowledge, this investigation provides the first CPM to predict UE SRI in college baseball players. Ideally, our results should be viewed in direct comparison to other multifactorial baseball injury prediction models. In the absence of other baseball specific CPMs, it is important to contextualize our model with respect to other SRI diagnostics (Bruce & Wilkerson, 2010b; Wilkerson, 2010) and traditional UE diagnostic models (Altman et al., 1990; Litaker, Pioro, El Bilbeisi, & Brems, 2000; Park, Yokota, Gill, El Rassi, & McFarland, 2005; Wainner et al., 2005).

Our study was initially modeled from the preliminary works of Bruce &Wilkerson (2010) and Wilkerson (2010) who developed CPMs specifically for athletic training. Their CPMs were developed by combining select FPM and self-report outcome measures in single center cohorts for retrospectively predicting UE overuse injury in collegiate softball players (Bruce & Wilkerson, 2010b) and prospectively predicting core and lower extremity strains and sprains in collegiate football players (Wilkerson, 2010). Although we included FPMs as potential predictor variables, our final two-factor CPM did not include modifiable functional parameters such as the side bridge hold (Bruce & Wilkerson, 2010b), trunk flexion hold (Bruce & Wilkerson, 2010b; Wilkerson, 2010), and wall-sit hold (Wilkerson, Bullard, & Bartal, 2010). Our study and Wilkerson (2010) both included regionally specific self-report functional outcome measures, the KJOC-SES, and Oswestry Disability Index respectively. With respect to diagnostic utility, our model yielded stronger measures for Sn, Sp, and LR+ and comparable LR- to Bruce & Wilkerson (2010) and Wilkerson (2010) (see Table 31).

Traditionally, UE SRIs are diagnosed through a clinical examination sequence that includes patient history and orthopedic special tests. Clusters of special tests have been combined to improve the accuracy of the clinical examination finding. Several CPMs comprised of special test clusters have been developed to diagnose pathologies (Altman et al., 1990; Litaker et al., 2000; Park et al., 2005; Wainner et al., 2005). With respect to the diagnostic utility of CPM special test clusters, our two-factor CPM demonstrated comparable of Sn, Sp, LR+, and LR- measures (see Table 31).

Table 31. Diagnostic Utility of CPMs

Study	Sensitivity	Specificity	LR+	LR-	Evidence Level*
SRI Prediction Models					
Bruce et al. (2010)					
	0.42 (0.19, 0.68)	0.96 (0.79, 0.99)	9.58 (1.3, 73.0)	0.61 (0.4, 1.0)	IV
Wilkerson et al. (2012)					
	.62 (0.46 - 75)	.91 (0.79 - 0.96)	6.8[a]	0.09[a]	IV
Current Investigation					
	0.83 (0.55 0.95)	0.95 (0.79 - 0.99)	22.0 (2.88 - 138.5)	0.17 (0.04 - 0.61)	IV
Diagnostic Special Test Clusters: UE Diagnostic Models					
Altman et al. (1990)					
	88%[b]	93%[b]	12.5[a]	0.07[a]	III
Litaker et al. (2000)					
	49%[b]	95%[b]	9.8[b]	0.05[b]	III
Wainner et al. (2005)					
	0.18 (.03 – .31)	0.99 (0.97 – 1.0)	18.3 (1.0 – 328.3)	0.18 (.03 – 0.31)	IV
Park et al. (2005)					
†	NR	NR	10.56[b]	0.17[b]	IV
‡	NR	NR	15.57[b]	0.16[b]	IV

Note. Value (95% Confidence Interval); LR+ = positive likelihood ratio; LR- = negative likelihood ratio; * CPM evidence level adapted from Glynn & Weishbach (2011); [a] Likelihood ratios not reported, calculated from Sn and Sp; [b] 95% confidence intervals not reported; Bruce et al. (2010) two-factor model for UE overuse injury in intercollegiate softball players (n = 35); Wilkerson et al. (2012) ≥3 factor model for core and LE strains and sprains in collegiate football players (n = 83); Altman et al. (1990) five-factor model for the diagnostic classification of osteoarthritis of the hand (n = 194); Litaker et al. (2000) three factor model for diagnosing rotator cuff tears (n = 448); Wainner et al. (2005) ≥ 4 factor model for diagnosing carpal tunnel syndrome (n = 82); Park et al. (2005) (n =1127) † three-factor model for diagnosing impingement syndrome, ‡ three-factor model for diagnosing full thickness rotator cuff tears.

This indicates that our CPM's diagnostic utility characteristics fall within a range acceptable for clinical practice. Collectively, the diagnostic utility of our CPM was clinically useful in delineating between injured and non-injured athletes based on retrospective analysis of UE SRI. The model correctly classified 85.5% of the cases (81.8% for the injured and 87% for the non-injured). The combination of these diagnostic utility measures indicates that the two-factor CPM may be an excellent diagnostic screening tool for both ruling in and ruling out UE SRI in collegiate baseball players.

Clinical Application

The results from this study may provide a number of benefits in advancing evidence-based clinical practice. First and foremost, we provided a review of diagnostic utility and their interpretive context for practicing clinicians. The concepts of Sn, Sp, LR+, and LR- are important for clinicians to understand with respect to diagnostic special tests and screening. Furthermore, clinicians need working knowledge of how diagnosticutility measures relate to pre-test and post-test probability in forming a clinical diagnosis. Clinicians who have a stronger understanding of diagnostic utility measures and know how to interpret them may improve their clinical reasoning skills in evaluating pathologies. Specifically, diagnostic tests and screening with dichotomous outcomes need to be interpreted and applied beyond elemental reasoning grounded in binary outcomes; (e.g., a positive test automatically equates to the presence of a given pathology). In the process of a clinical assessment sequence, a clinician should consider procedures that have high diagnostic utility and eliminate ones of little value (Denegar &

Cordova, 2012). Once a clinician knows the diagnostic metrics of a special test or screen, the results need to be contextualized based on pre-test and post-test probabilities. Clinicians who have an improved ability to interpret clinical findings may arrive at more conclusive clinical diagnoses. Such an approach is a departure from clinical reasoning anchored in experience that is based in heuristics (Kassirer, Wong, & Kopelman, 2010). In day-to-day clinical practice, heuristics are a problem solving short cut predicated upon one's experience in recognizing general diagnostic patterns with respect to a given pathology. To some extent pattern recognition relies on the likelihood of an event based on the typical clinical presentation of a hypothesized pathology. This may serve a clinician well when a patient presents with classic signs and symptoms or in emergency situations when time is limited, but is prone to error in complex or atypical cases (Kassirer et al., 2010). Because of the risks of misdiagnosis, it is important for clinicians to use clinical reasoning skills consistent with the application and interpretation of appropriate diagnostic tests and screenings. This study provides a link between definitional concepts and interpretations of diagnostic utility measures that may facilitate clinical reasoning skills consistent with the evidence-based paradigm.

Our CPM is a preliminary model based on a retrospective analysis of a single-center cohort. As a derivation stage model, the CPM should undergo additional validation and impact analysis as part of the development process before being generalized beyond the original sample (Portney & Watkins, 2009). However, the model was consistent with the literature on two foundational points: (a) pitchers are at higher risk of UE SRI than field position players (Dick et al., 2007; Fleisig et al., 2010;

McFarland & Wasik, 1998); and (b) KJOC-SES were able to predict injury status (Alberta et al., 2010; Domb et al., 2010; Neri et al., 2010; Neuman et al., 2011). The standard for determining positive functional outcomes in baseball athletes has historically been return-to-play; however, the standard of return-to-play does not adequately quantify an athlete's functional status (Alberta et al., 2010). Pragmatically, our results support the notion that clinicians should incorporate self-reported outcome measures as a compulsory element of clinical practice. This form of clinical outcome assessment is foundational to EBP and should be a standard component of patient care (Sauers & Snyder, 2011). A clinician could easily incorporate our CPM as part of the pre-participation physical process or the injury evaluation and rehabilitation examination sequence when working with baseball athletes. The self-report outcomes assessments should be a routine part of clinical practice. Most clinicians (90%) recognize the importance of self-reported outcome measure; however only 48% of physical therapists incorporate them as part of patient assessment (Jette, Halbert, Iverson, Miceli, & Shah, 2009). The use of self-reported outcome measures among athletic trainers is unknown (Michener, 2011).

Beyond the aforementioned direct application, our study builds on the theoretical framework for developing CPMs in athletic populations to predict SRI (Bruce & Wilkerson, 2010a). Developing injury prediction models similar to ours and others (Bruce & Wilkerson, 2010b; Wilkerson, 2010) may be advantageous in other populations to gain knowledge related to risk factors and SRI. Simplistically, an athletic trainer could develop a CPM as part of a retrospective injury analysis as seasons end to determine risk factor patterns. On a more complex level, researchers could partner with clinicians to

work collaboratively in developing CPMs to enhance clinical practice. If coupled with measures of diagnostic utility, practitioners could find themselves at the nexus of patient-centered evidence-based clinical practice.

Collectively, the principles of evidence-based practice have emerged as an important focus within sports medicine clinical practice. Clinicians should possess a skill set in understanding and applying diagnostic utility measures. Employing CPMs to understand the relationship between multiple risk factors and injury are vital for improving diagnosis as well as treatment based prognosis. The addition of self-reported outcome measures is also an important element of clinical practice that is beneficial in quantifying the heath and injury status of athletic populations. Thus the scope of this study advances the body of knowledge in these areas of evidence-based clinical practice which is central to 21st century health care (Evans & Lam, 2011).

Limitations

There are a number of limitations associated with this study that warrant consideration, particularly retrospective methodology, FMS reliability, and sample size. Researchers may not be able to control the completeness or reliability of the data collection process in retrospective studies (Portney & Watkins, 2009). Individual game-by-game statistics were only available for 11 of the 19 (58%) pitchers and eight of 17 (47%) fielders. This reduced the sample size for univariate analysis for the majority of sport performance risk factors (see Table 13). Secondly, CKCUEST data were missing for two subjects, both pitchers, one with a history of UE SRI. The reason for the missing data is unknown, but could have resulted from subject refusal to participate in the

individual FPM, a data recording error, or database entry error. Subsequently this reduced the sample size from 36 to 34 for univariate analysis related to CKCUEST (absolute score) and CKCUEST (TEAM-S). The multivariate analysis treated the data set associated with these two subjects as missing cases and excluded them the logistic regression statistical modeling. Analysis of an incomplete data set may have influenced our findings.

With respect to reliability, the TEAM-S was used to generate predictor variables related to FPM. As a new battery of functional performance screening measures, TEAM-S does not have established reliability or validity metrics. Although the reliability of TEAM-S is unknown, the individual tests that comprise the battery are similar to tests comprising the FMS® and the FROHM 9-Test Screen. FMS® and the FROHM 9-Test Screen have been shown to be reliable (Frohm et al., 2011; Minick et al., 2010; Schneiders et al., 2011; Teyhen et al., 2012). Additionally, it is important to recognize that the individual tests comprising the TEAM-S have established reliability metrics (see Table 6). Ideally, FPM data should have been obtained from a battery of tests with an established composite score reliability. However, this study was only able to obtain FPM through the TEAM-S process.

The TEAM-S was administered in a field rather than a laboratory setting by experienced (physical therapists, certified athletic trainers, certified strength and condition coaches) and novice (undergraduate students) clinician/raters with minimal training. The intra- and inter-rater reliability for experienced and student raters was not determined prior to data collection. For the most part, individual FPMs have previously

demonstrated good to excellent intra- and inter-rater reliability among clinicians with varied experience (Minick et al., 2010; Teyhen et al., 2012).

Sample size is critical with respect to the number of positive cases and the number of included predictive variables (Pallant, 2010). It is common practice to include 10 to 15 subjects per predictor variable in the final CPM (Glynn & Weisbach, 2011), but a larger sample size to account for 10 to15 subjects per potential predictor variable in the overall study has been suggested to avoid over-fitting a regression model (Beneciuk, Bishop, & George, 2009). In the current investigation (n = 36) there were twelve positive cases with five predictor variables entered into the logistic regression, which resulted in a two-factor CPM. Our final model is within the constraints of 10 to 15 subjects per factor in the final model, but inconsistent with the suggested 10 to 15 subjects per predictor variable within the overall study. A larger sample size would likely be beneficial in strengthening the development of a CPM on the basis of greater statistical power. Specifically, the model demonstrates strong diagnostic utility measures; however, the 95% confidence intervals associated with LR+ (2.88 to 138.5), LR- (0.04 to 0.61), and DOR (9.32 to 1418.8) are wide. A larger sample size would narrow the 95% confidence intervals and the accuracy of the diagnostic utility measures (Bruce & Wilkerson, 2010b).

In addition to these primary concerns, other limitations should be considered. Injury status as the dependent outcome variable was established from self-reported history as part of the KJOC-SES instrument. The KJOC-SES does not establish a time-course for injury occurrence nor does the instrument provide an operational definition for what constitutes an UE SRI. Additionally, the instrument requires ten response items

without temporal context. The items require a respondent to quantify a perception without providing a time frame (e.g., with the past month or with the past year). The lack of temporal context requires a respondent unconsciously to use subjective impressions of stability and change to derive an interpretive response that may be unrelated to the intent of the instrument's context (Streiner & Norman, 2008). This may bias item responses, causing measurement error or undermining the measurement scale's reliability (DeVellis, 2003). Consequently, the recall accuracy of self-report health measures is an issue in health measurement scale methodology (Streiner & Norman, 2008). This may be particularly true in disorders with fluctuating symptoms (e.g., osteoarthritis, depression) or when pain is a primary variable (Litcher-Kelly, Martino, Broderick, & Stone, 2007; Stone, Broderick, Kaell, DelesPaul, & Porter, 2000; Stone, Broderick, Shiffman, & Schwartz, 2004). However, recall accuracy of self-reported sport injury history in athletes has been reported to be 80% (Gabbe, Finch, Bennell, & Wajswelner, 2003).

An additional concern related to SRI history is the number and type of injuries that were reported in our cohort. Twelve (33%) of the participants had a self-reported history of a serious UE SRI: five ulnar collateral ligament sprains, three shoulder impingements, two labium pathologies, and two rotator cuff tendinopathies. The nature of these self-reported injuries was consistent and representative of time-loss UE SRI reported in literature (Burkhart, 2006; Burkhart, Craig, & Kibler, 2003; Burkhart & Morgan, 2001; Cain et al., 2003; Domb et al., 2010; Gerstman et al., 2009; Jazrawi et al., 2006; Jobe & Bradley, 1988; Kuhn, 2009; Namdari et al., 2011; Wood et al., 2010). The current retrospective reporting of a 33% injury rate was similar to the 25% injury rate

previously reported in collegiate baseball (Dines et al., 2007). Typically, sport injury rates are expressed as a ratio of injures per 1,000 units of practice and/or game exposures. Because of the nature of this retrospective study, we were unable to calculate an injury rate per 1,000 exposures to determine whether our injury rate was consistent with reported values of 0.54 to 5.73 per 1,000 (Dick et al., 2007; Posner et al., 2011). It is important to consider that injury prevalence in the context of a small sample size may not reflect well the prevalence in a larger population (Portney & Watkins, 2009). Thus caution is warranted in placing the results of this investigation into a broader context. Despite the existence of these limitations, the study fits within in the context of derivation stage CPM. Our primary findings are consistent with current evidence related to UE SRI in baseball players. The strength of our two-factor CPM warrants consideration in an appropriate context and provides a foundation for future research.

Recommendations for Future Research

The current findings resulted in a preliminary two-factor CPM comprised of KJOC-SES (≤ 86) and playing position (pitcher). The model was developed in a small sample ($n = 36$) pooled from a single center. It appears that the CPM is a viable clinical screening tool for UE SRI in baseball players. However, the model is only consistent with a level IV evidence rating for CPM and should undergo additional development to address issues related to sample size, validity, and impact analysis (Portney & Watkins, 2009).

The natural progression for CPM development after the derivation stage is validation and impact analysis (Childs & Cleland, 2006; Toll, Janssen, Vergouwe, &

Moons, 2008). Validation encompasses reproduction of the CPM to assess the model's metrics in a different or expanded population set. Validation also may entail conformation of the original set of predictor variables or consideration of alternative variables that were excluded from the initial design. On a basic level, our CPM and its diagnostic utility metrics need to be conformed in a larger sample. This should occur in a prospective design to determine whether the retrospective diagnostic properties of the model are transferable to a prognostic screening tool.

The greater challenge of validating the model would be to update the preliminary set of contributory variables (Toll et al., 2008). Our predictor variables were derived from the KJOC-SES, sport performance statistics, and the TEAM-S. Due to the availability of retrospective data, we obviously could not address the full spectrum of risk factors previously identified as causal for UE SRI in baseball athletes. Specifically, we did not include direct measurements of muscle strength deficits (Brown et al., 1988; Yildiz et al., 2006), muscle fatigue (Mullaney et al., 2005), internal and external strength imbalance (Lewis & Valentine, 2007), GIRD (Borsa et al., 2006; Dines et al., 2009; Wilk et al., 2010), maximum pitching velocity (Bushnell et al., 2010), or throwing biomechanics (Fleisig et al., 1995; Fleisig et al., 1996). Conceptually we categorized risk factors into three areas consisting of (a) self-reported outcome scores; (b) sport performance factors; and (c) FPM. Future studies should include direct measures such as muscle strength deficits, muscle fatigue, internal and external strength imbalance, GIRD, maximum pitch velocity, or biomechanics. This may improve understanding of the multifactorial relationship between risk factors and UE SRI. It may generate a different

model that includes a set of modifiable predictor variables (e.g., strength imbalance, ROM deficits) that could translate into a specific injury prevention program.

In addition to the recommendation for expanding the number of risk factors, it is important to consider the role of FPM in clinical research. Our results provide additional confirmation on the lack of evidence between FPM batteries and injury prediction. Future work in this area should focus on clarifying the TEAM-S normative values and envelope of function. This may contribute to establishing the reliability and validity of TEAM-S in identifying functional limitations and injury risk in athlete populations.

Impact analysis of CPM pertains to how a model is utilized by clinicians, affects clinical decision making, and improves patient outcomes (Toll et al., 2008). The fundamental issue relating to impact analysis centers on sensibility and begs the question: "Can a CPM be easily incorporated into route clinical practice, produce interpretable results, and lead to tangible patient-oriented outcomes?" (C. E. Cook, 2008). One might assume that our two-factor CPM could be incorporated easily into clinical practice as a pre-season baseline measure. However, the use of self-report outcome measures has been lacking in sports medicine settings such as athletic training. Translational research may help orient clinicians to how a CPM can be implemented and applied in sports injury management and rehabilitation. This in turn may lead to evidence that demonstrates how a CPM shapes clinical decision making and leads to improved patient-oriented outcomes.

The logical next step in our research centers on two potential approaches, the first of which is to employ the KJOC-SES as a prognostic screening tool. Through retrospective design, the KJOC-SES has demonstrated respectable diagnostic utility in

identifying overhead athletes with UE SRI and self-reported functional limitations. The question that remains is whether the KJOC-SES can predict injury prospectively. Investigating this question would benefit identifying individual athletes for preventive treatment strategies. Second, the work of Wilkerson (2010) provides evidence that self-reported outcome measures coupled with select FPMs that assess altered neuromuscular activation patterns (e.g., muscular endurance fatigue) are supported as a preseason injury-risk screening tool in collegiate football players. A similar approach in baseball athletes has not yet been established. Moving forward, research that combines the KJOC-SES with modifiable neuromuscular risk factors may provide a more definitive CPM in predicting UE SRI in baseball players.

Conclusion

Based on the findings of this study, a preliminary two-factor CPM comprised of KJOC-SES (≤ 86) and playing position (pitcher) retrospectively predicted UE SRI in a cohort of baseball players with strong diagnostic utility. The CPM demonstrated greater diagnostic utility than did individual risk factors in predicting UE SRI in injured versus non-injured groups. Although retrospective designs and derivation models have limitations, the two-factor CPM improves on current understanding of risk factors and UE SRI in baseball. The diagnostic utility measures for the two-factor CPM in this population have not been reported previously and comprise a novel approach to injury evaluation consistent with the evidence-based paradigm.

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APPENDIX A

KERLAN-JOBE ORTHOPAEDIC CLINIC SHOULDER & ELBOW SCORE

(KJOC-SES)

Overhead Athlete Shoulder & Elbow Score

Name_____ Age_____ Sex_____

Dominant Hand (R) _____ (L) _____ (Ambidextrous) _____

Date of Examination_____

Height (ft/in)_____ Weight(lbs) _____

Sport _____ Position _____ Years Played _____

Please answer the following questions related to your history of injuries to *YOUR ARM ONLY*:

	YES	NO
1. Is your arm currently injured?	☐	☐
2. Are you currently active in your sport?	☐	☐
3. Have you missed game or practice time in the last year due to an injury to your shoulder or elbow?	☐	☐
4. Have you been diagnosed with an injury to your shoulder or elbow other than a strain or sprain? **If yes, what was the diagnosis? _____**	☐	☐
5. Have you received treatment for an injury to your shoulder or elbow?	☐	☐

If yes, what was the treatment? (Check all that apply)

☐ Rest ☐ Therapy ☐ Surgery (please describe): _____

Please describe your level of competition in your current sport:
(Use Professional Major League, Professional Minor League, Intercollegiate, High School as the choices)

6. What is the highest level of competition you've participated at?_____
7. What is your current level of competition? _____

8. If your current level of competition is not the same as your highest level, due you feel it is due to an injury to your arm?	☐	☐

Please check the ***ONE category only*** that best describes your current status:

☐ Playing without any arm trouble ☐ Playing, but with arm trouble

☐ Not playing due to arm trouble

Instructions to athletes:

The following questions concern your physical functioning during game and practice conditions. Unless otherwise specified, all questions relate to your ***shoulder or elbow***. Please answer with an **"X"** along the horizontal line that corresponds to your current level.

1. How difficult is it for you to get loose or warm prior to competition or practice?

Never feel loose during games or practice — **Normal warm-up**

2. How much pain do you experience in your shoulder or elbow?

Pain at rest — No pain with competition

3. How much weakness and/or fatigue (i.e. loss of strength) do you experience in your shoulder or elbow?

Weakness or fatigue preventing any competition — No weakness, normal competition fatigue

4. How unstable does your shoulder or elbow feel during competition?

"Popping out" routinely — No instability

5. How much have arm problems affected your relationship with your coaches, management, and agents?

Left team, traded or waived, lost contract or scholarship — Not at all

The following questions refer to your level of competition in your sport. Please answer with an **"X"** along the horizontal line that corresponds to your current level.

6. How much have you had to change your throwing motion, serve, stroke, etc. due to your arm?

Completely changed, don't perform motion anymore — No change in motion

7. How much has your velocity and/or power suffered due to your arm?

Lost all power, became finesse or distance athlete — No change in velocity/power

8. What limitation do you have in endurance in competition due to your arm?

Significant limitation (became relief pitcher, switched to short races for example) — No endurance limitation in competition

9. How much has your control (of pitches, serves, strokes, etc.) suffered due to your arm?

Unpredictable control on all pitches, serves, strokes, etc. — No loss of control

10. How much do you feel your arm affects your current level of competition in your sport (i.e. is your arm holding you back from being at your full potential)?

Cannot compete, had to switch sports — Desired level of competition

APPENDIX B

TARGETED ENHANCED ATHLETIC MOVEMENT SCREEN (TEAM-S)


HIGH POINT
UNIVERSITY
T E A M
TARGETED ENHANCED ATHLETIC MOVEMENT

Athlete's Name:

Date today:

Date of Birth:

Age: **Gender (circle one):** **Male Female**

Sport:

Position:

Year in School:

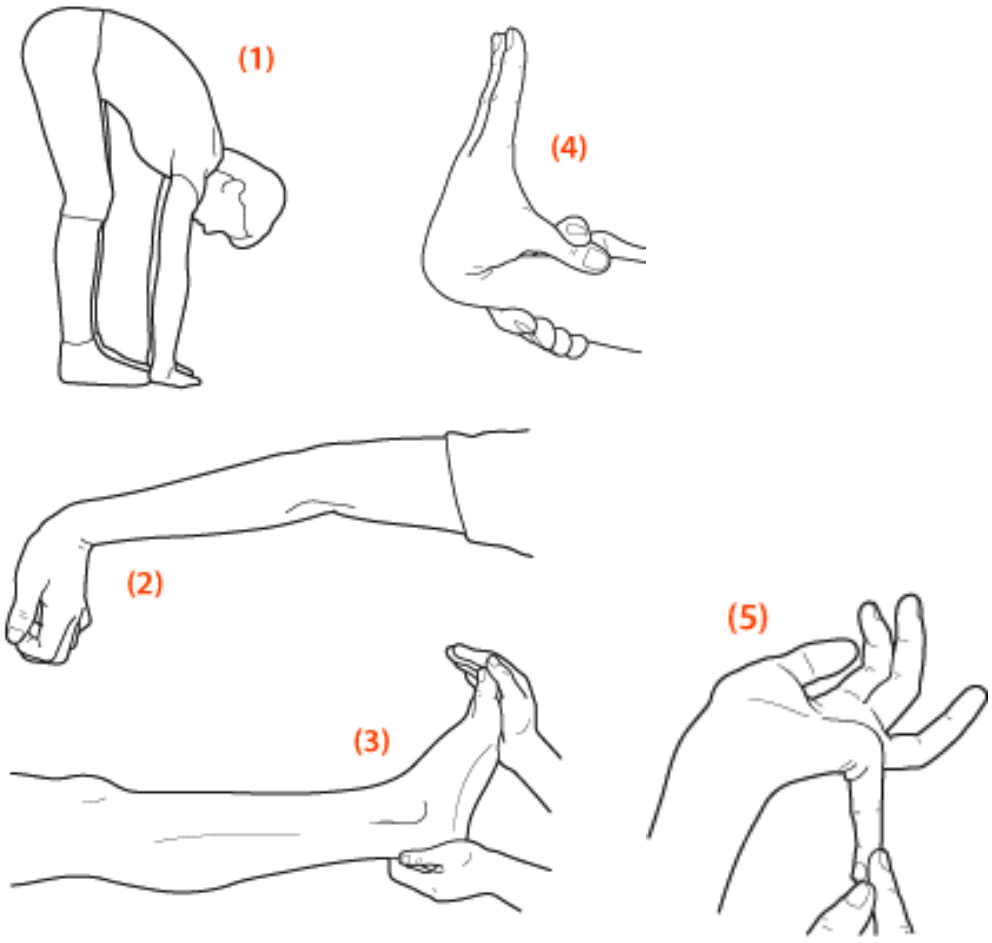
TOTAL SCORE: _____/75

X 100= _____%

Scoring is done by taking the score of each individual test and adding them together. If the test has more than 1 score (ex: left and right scores) then the LOWEST of those scores is taken to compute the overall TOTAL SCORE.

SCORING SHEETS

1. BEIGHTON HYPERMOBILITY



	L	R
Hands on the floor with knees straight	**1**	
Elbow hyperextension	**1**	**1**
Knee hyperextension	**1**	**1**
Thumb to forearm	**1**	**1**
Little finger 90 degrees or more	**1**	**1**
TOTAL		**_____/9**

points	0-1	2-3	4-5	6-7	8-9	pain
SCORE	**5**	**4**	**3**	**2**	**1**	**0**

2. FULL SQUAT

Description:
3 reps to allow views from different angles
PVC overhead and 2x4 under heels as needed. Feet shoulder width apart, toes point straight ahead, heels stay on ground, squat below parallel

Common Errors: Knees to midline, heels come off ground, shoulders flex forward, lean left or right, toes rotate out

Score (check one):		**COMMENTS:**
Full squat (below 90), no substitutions	5	
Squat to parallel, no substitutions	4	
Full squat with 2x4 no substitutions	3	
Squat to parallel with 2x4, no substitutions	2	
Unable to squat without substitutions to parallel even with a 2x4	1	
Pain with test	0	

3. SINGLE LEG SQUAT

Description:

5 reps with worst of last 2 reps scored. Subject stands on 1 leg and touches their rear to a stool, then stands back up. The stool is at a height where the squat is parallel to the floor (90 deg). Watch for the common errors listed below

Common Errors: Loss of balance, knees to midline, lack of depth, toe in/out, lateral trunk lean

Score (check one):			**COMMENTS:**
	L	R	
0-1 error present	5	5	
2 errors present	4	4	
3 errors present	3	3	
4 errors present	2	2	
5+ errors present	1	1	
Pain with test	0	0	

4. Downward Dog

Description:

Start on all fours, knees under hips and hands one hand length in front of shoulders. Straighten legs and arms, flattening scapula to back forming and inverted V.

Common Errors: heels don't touch ground, inverted U shape

Score (check one):		**COMMENTS:**
patient able to touch heels to floor and assume inverted V position	5	
both heels to floor with adjusted hand position, and flat back	4	
both heels to floor with adjusted hand position and rounded back	3	
one heel to floor with other leg lifted straight back	2	
unable to get heel to floor with one leg lifted straight back	1	
Pain with test	0	

5. Active Straight Leg Raise

Description:

Patient lays on back with legs straight, toes pointing toward ceiling and 2x4 under knees. Arms flat on ground. Instruct subject to lift their leg keeping it straight. Examiner places dowel in line with the medial malleolus. Test is named for the leg lifted

Common Errors: bent knee on either leg, leg rotates outward (either leg)

Score (check one):			**COMMENTS:**
	L	R	
dowel lines up with greater trochanter (GT) or above (90+degrees of hip flexion)	5	5	
dowel lines up between mid-thigh and GT	4	4	
dowel lines up between patella and mid-thigh	3	3	
dowel lines up between patella and mid-shin	2	2	
dowel lines up below mid-shin	1	1	
Pain with test	0	0	

6. Shoulder Mobility Test

Description:

First, measure the patient's hand length from the wrist crease to the tip of the middle finger and record below. The test is named for the arm that is behind the back. Make a fist and reach behind the head as far as possible. Make a fist with the opposite hand and reach behind the back as far up as possible

Common Errors: trying to "crawl" the hands closer together, scapular winging, poor motion

HAND LENGTH: L _____ R_____

Score (check one):			**COMMENTS:**
	L	R	
fists touch without scapular winging	5	5	
fists within one hand length no winging	4	4	
fists within one hand length or closer with winging	3	3	
fists between 1 and 2 hand lengths- with or without winging	2	2	
fists greater than 2 hand with or without winging lengths apart-	1	1	
Pain with test	0	0	

7. Y-Balance for UE

	Trial			**Description:**
Reach Direction	**1**	**2**	**3**	Measure C7 spinous process to longest fingertip with arm in 90 degrees abduction. Assume push-up position. 3 trials will be performed in each direction. All 3 directions (lateral, inferomedial, superomedial) performed without rest. The sum of the greatest reach in each direction is divided by 3x the limb length then multiplied by 100. Test is named for the non-reaching arm
Lateral	**L**	**L**	**L**	
	R	**R**	**R**	
Overhead				
Underneath				

Common Errors: trying to "crawl" the hands closer together, scapular winging, poor motion

LIMB LENGTH: L _____ R_____

Sum of greatest 3 reaches: L_____/3 x 100= _____

R_____/3 x 100= _____

Score (check one):		**COMMENTS:**
one arm 95%-100% of the other	5	
One arm 90%- 94% of the other	4	
One arm 85%- 89% of the other	3	
One arm 80%- 84% of the other	2	
One arm 79% or less of the other	1	
Pain with test	0	

8. CKCUEST

Description:

2 pieces of tape 36 inches apart. Athlete places their arms in a shoulder width, push-up position between the pieces of tape. Athlete alternates touching the pieces of tape. Record # of cross-body touches in 15 sec

Common Errors: poor quickness

Score (check one):		**COMMENTS:**
patient able to touch 30+ times	5	
patient able to touch 25-29 times	4	
patient able to touch 20-24 times	3	
patient able to touch 15-19 times	2	
patient able to touch 14 or less times	1	
Pain with test	0	

9. Side Plank Hip Abduction

Description:

Subject is in a side plank position on elbow with feet together and opposite hand on hips. Only bottom foot (not leg) and elbow should touch the ground. Lift top leg at least 8 inches and return to start as many times as possible in 30 sec. Rest 2 minutes, and repeat on the opposite side. Test is named for the leg lifted

Common Errors: top leg cannot be lifted, top leg flexes forward during test, entire lower leg of bottom leg touches the ground, trunk flexes

Score (check one): **COMMENTS:**

	L	R
30+ reps	5	5
25-29	4	4
20-24	3	3
15-19	2	2
14 or less	1	1
Pain with test	0	0

10. Side Plank Hip Adduction

Description:

Subject is in a side plank position on elbow with one foot touching the ground and the other resting on a bench. Or chair The opposite hand rests on hips. Only bottom foot (not leg) and elbow should touch the ground. Lift bottom leg at least 8 inches and return to start as many times as possible in 30 sec. Rest 2 minutes, and repeat on the opposite side. Test is named for the leg lifted

Common Errors: bottom leg cannot be lifted, bottom leg flexes forward during test, entire lower leg of bottom leg touches the ground, trunk flexes

Score (check one):		**COMMENTS:**
	L	R
35+ reps	5	5
30-34	4	4
25-29	3	3
20-24	2	2
23 or less	1	1
Pain with test	0	0

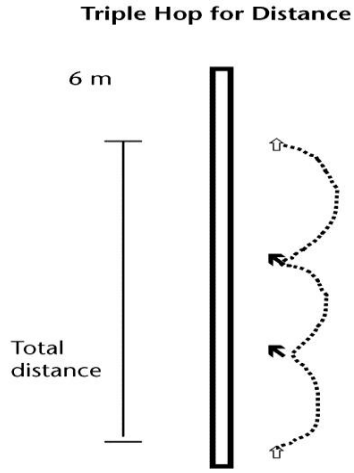
11. Nordic Hamstring Test

Description:
Subject kneels and examiner holds ankles. Keeping a perfectly straight body with arms at the ready (push-up position), the subject leans slowly forward. Examiner measures knee flexion angle at failure (athlete lets go)

Common Errors: butt sticks out, trunk flexes, hamstring cramp

Score (check one):		**COMMENTS:**
45 degrees +	5	
35-44 degrees	4	
25-34 degrees	3	
15-24 degrees	2	
5-14 degrees	1	
Pain with test or less than 5 degrees	0	

12. Triple Hop for Distance



Description:

Measure leg length in standing from ASIS to beneath the lateral malleolus. Hands on hips, jump and land 3 consecutive times on the same leg**. Each athlete may have one practice trial. They must stick the landing.** Record the total distance jumped on each leg. The hop will he measured from the starting line to the back of the heel after the third hop on each trial.

Common Errors: use of hands, fall off balance

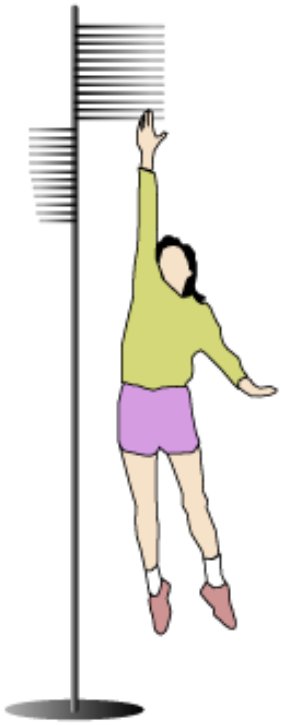
LIMB LENGTH: L _____ R_____

Distance hopped: L_____ R_____

Least distance/greatest distance x 100= _____

Score (check one):		**COMMENTS:**
one leg 95%-100% of the other	5	
One leg 90%- 94% of the other	4	
One leg 85%- 89% of the other	3	
One leg 80%- 84% of the other	2	
One leg 79% or less of the other	1	
Pain with test	0	

13. Vertical Leap



Description:

First, record stand-and-reach height by having the participant extend the preferred reach hand as high as possible with feet flat on the floor. Subject should bend the hips and knees, and, without pausing, jump as high as possible. Arm swing is allowed. Record jump-and-reach height. VJ height is calculated by subtracting the stand-and-reach height from the jump-and-reach height. Participants are permitted 1 practice jump before completing 3 test trials. The maximal height reached during the 3 test trials is recorded.

Common Errors: any steps taken

(a)Stand and reach height: _____in. (b)Jump and Reach Height: _____in.

VJ Height: (b) – (a) _____in.

Score (check one):		**COMMENTS:**
Men- 30+ in.	5	
Women- 20+ in.		
Men- 26-29 in.	4	
Women- 16-19 in.		
Men- 22-25 in.	3	
Women- 12-15 in.		
Men- 18-21 in.	2	
Women- 8-11 in.		
Men- 17 or less in.		
Women- 7 or less in.	1	
Pain with test	0	

14. In-Line Lunge for Distance

Description:

First, measure leg length from beneath the ASIS to beneath the lateral malleolus. Toes are behind a line on the floor, hands on hips. Subject steps out as far as possible with one leg while toe of the other leg must stay behind the start line. Measure distance by heel of the lead leg. Take the best of 3 trials for each leg. **The test is named for the trail leg**

Common Errors: dragging the rear foot forward, losing balance

LIMB LENGTH: L _____ in. R_____ in.

Distance Lunged: L_____ in. R_____ in.

Score (check one):			**COMMENTS:**
	L	R	
one leg 95%-100% of the other	5	5	
One leg 90%- 94% of the other	4	4	
One leg 85%- 89% of the other	3	3	
One leg 80%- 84% of the other	2	2	
One leg 79% or less of the other	1	1	
Pain with test	0	0	

15. Lateral Lunge for Distance

Description:

First, measure leg length from beneath the ASIS to beneath the lateral malleolus. Medial aspect of trail leg is behind a line on the floor, hands on hips. Subject steps out as far as possible with one leg while foot of the other leg must stay behind the start line and flat to the floor. Measure distance by the medial border of the lead leg (toes pointing straight ahead). Take the best of 3 trials for each leg.

The test is named for the trail leg

Common Errors: dragging the rear foot forward, losing balance, rotating the lead foot outward

LIMB LENGTH: L _____ in. R_____ in.

Distance Lunged: L_____ in. R_____ in.

Score (check one):		**COMMENTS:**
	L	R
one leg 95%-100% of the other	5	5
One leg 90%- 94% of the other	4	4
One leg 85%- 89% of the other	3	3
One leg 80%- 84% of the other	2	2
One leg 79% or less of the other	1	1
Pain with test	0	0

APPENDIX C

HIGH POINT UNIVERSITY INSTITUTIONAL REVIEW BOARD PROTOCOL APPROVAL

HUMAN PARTICIPANTS INSTITUTIONAL REVIEW BOARD
HIGH POINT UNIVERSITY
833 Montlieu Avenue • High Point, North Carolina 27262-3598 • (336) 841-9000

August 10, 2011

Eric J Hegedus and Dan Tarara
Physical Therapy
Campus Drawer 23

RE: **Protocol #201107-074: *Physical performance screening measures and their correlation with injury***

The High Point University Institutional Review Board (IRB) has reviewed and approved this research protocol under an expedited review.

If you require any modifications that alter methodology in a substantial way, change the Principal Investigator (PI) or Co-Investigator(s), or any changes in the selection of your participants, you must notify the IRB before implementing the modifications as required. To report changes, you must submit a new protocol application form.

Although the project is approved for three years, an annual report must be filed one year from the above approval date (continuing review form). Upon completion of the project, you must submit a final report along with the study closure form. This must be submitted to the IRB by August 10, 2014.

The IRB approved consent form must be used for all informed consent procedures on all human subjects in this study. The signed consent forms must be kept under lock and key on university property for the duration of the study plus three years. These consent forms are subject to inspection during this time period by the IRB. A copy of the consent must be provided to each subject participating in the study.

All investigators listed in this protocol must maintain current human subjects training certificates for the duration of the study. The certificates submitted with the protocol application are active for one year only. Therefore, they must be renewed with the annual report.

If you have any questions related to this research or to the IRB, you may contact me at (336) 841-9246.

Sincerely,

Dr. Kimberly Wear
Associate Professor of Psychology
IRB Chair

APPENDIX D

INFORMED CONSENT FORM

Protocol #201107-074:
Physical performance screening measures and their correlation with injury.

CONSENT TO PARTICIPATE IN A RESEARCH STUDY:

You are being asked to take part in this research study because you are a student-athlete at High Point University. Research studies include only people who choose to take part. Please read this consent form carefully and take your time making your decision. As your study doctor or study staff discusses this consent form with you, please ask him/her to explain any words or information that you do not clearly understand. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

What the study is about:

- The purpose of this study is to determine whether certain tests (pre-season strength and conditioning screen) or other information from my standard pre-season physical correlate with injury or with certain performance factors.

What you will be asked to do:

If you agree to be in this study, you will be asked to sign this consent form. You will be allowing access to records including:

- Physical exam and medical history
- Vital signs
- Blood tests
- Pre-season strength and conditioning screen results

What good will come from the study:

We hope to be able to gather information that will help us predict injury and performance. If we can predict injury in athletes, then we can institute exercises and other interventions that can prevent those injuries and improve performance.

Important Things to Know about Being Part of the Study

1. **You don't have to do this.** The release of the information gathered from the pre-season physical and strength and conditioning screen is completely voluntary and you can refuse to release the information if you would like. You also have the ability to not perform the strength and conditioning tests as a whole or any individual test. Nonparticipation or withdrawal from this study will not affect your student-athlete status, your grades or your standing with the team.

2. **Pay.** There is none for doing this. You are doing it for free.

3. **Risks to you.** Some subjects may report muscle soreness or fatigue during or after testing. The only inconvenience is your time to participate in the study although you would be receiving the pre-season physical and pre-season strength and conditioning screen anyway as part of your standard pre-season assessment. If you are hurt, you may seek treatment through Student Health Services in Wilson Hall (for full-time day students). Otherwise, you or your health care insurer will have to pay. If you have any questions about what your insurer will pay for, you should contact them.
4. **Your responses will be kept confidential.** Your name will not be stored with your responses and only those involved in the research project and the health care providers (nurses, doctors, and athletic trainers) will have access to the responses of individuals.
5. **If you have questions about the study.** For questions about the study or research-related injury, contact *Dr. Eric Hegedus, PT* at *(336-906-2133) or at ehegedus@highpoint.edu*.

Retrospective

Protocol #201107-074:
Physical performance screening measures and their correlation with injury.

6. **If you have questions regarding your rights as a subject in this study.** You may contact Dr. Kimberly Wear, IRB Chair, (336) 841-9246, kwear@highpoint.edu.

Statement of Consent: I have read the above information, and have received answers to any questions I asked. I agree to participate in this research study and am at least 18 years of age.

Signature: _____ Date: _____

Printed Name: _____

Person Obtaining Consent: I have explained to the above named individual the nature and purpose, the potential benefits and possible risks associated with participation in this research. I have answered any questions that have been raised and I will provide the participant with a copy of this consent form.

Signature: _____ Date: _____

Printed Name: _____

Retrospective

APPENDIX E

RECEIVER OPERATOR CHARACTERISTIC (ROC) CURVES

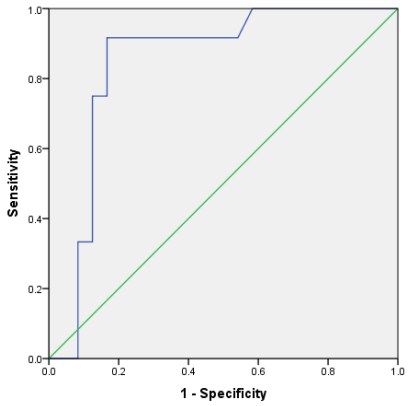


Figure E1. ROC Curve for KJOC-SES Score
AUC = 0.854.

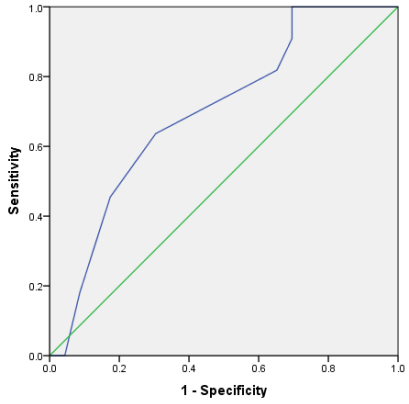


Figure E2. ROC Curve for CKCUEST Absolute Score
AUC = 0.698.